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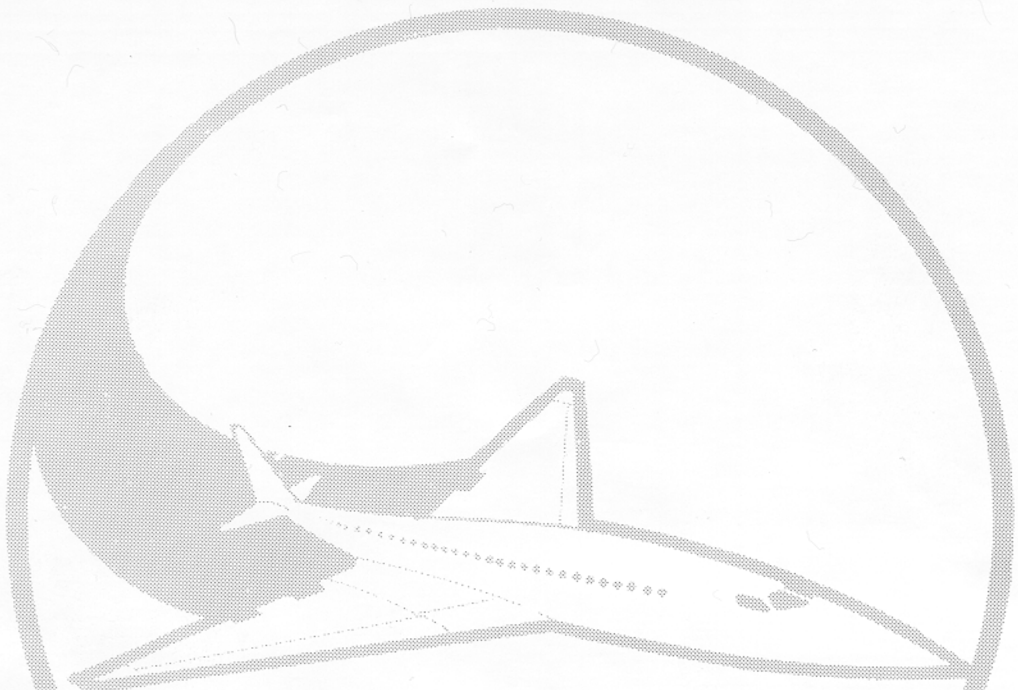
Reanalysis of European Flight Loads Data



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This work was performed under a memorandum of cooperation between the Federal Aviation Administration and the Netherlands Civil Aviation Department. As a part of this effort the National Aerospace Laboratory was contacted to participate in this research effort. The FAA technical manager is Tom DeFiore, ACD-220.

16. Abstract

The principle tasks of this research effort were to identify and acquire existing European flight loads data, to develop a unified procedure to reduce the acceleration data into gust statistics, and to reduce and analyze the data. Three data bases containing information on center of gravity acceleration experience of commercial transport aircraft were obtained and analyzed. A very large database containing data on aircraft operated by British Airways was obtained from the Office National d'etudes et de researches aerospatiales in France. A database kept at National Aerospace Laboratory, containing information on Boeing B-747 aircraft operated by KLM, SAS, and Swissair, was also used. The third database contains data collected several years ago by the Royal Aircraft Establishment for a wide variety of mainly piston-engine aircraft. The size of the combined database, corresponding to 870,000 flights, 1.6 billion kilometers, and 2 million flight hours.

A unified procedure was developed to reduce the data based on both discrete and continuous gust approaches. The results obtained show a considerably lower gust experience at higher altitude than predicted by currently used statistical models. At low altitudes, these results tend to agree with other statistical data. However, gust exceedance data at altitudes below 2000 feet were incomplete and partially biased by maneuver accelerations. Additional low altitude gust exceedance data are needed.

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A	= Aspect ratio = b^2/S	
$\bar{A}$	= Spectral response ratio	(s/m)
b	= Wing span	(m)
b_1, b_2	= gust intensity parameters for non-storm turbulence and storm turbulence (m/s EAS)	
c	= Wing chord	(m)
$\bar{C}$	= Discrete response ratio	(s/m)
C_{L_α}	= Aircraft lift curve slope (rad^{-1})	
C_L	= Aircraft lift coefficient	
Δn_z	= incremental load factor	
$F(\mu_g)$	= gust alleviation factor	
$F(PSD)$	= spectral gust alleviation factor	
μ_g	= Mass ratio, $\frac{2m}{\rho c\, C_{L\alpha}\, S}$	
h	= Altitude	(m or ft)
m	= Aircraft mass	(kg)
$N(0)$	= Number of zero crossings per km	(km^{-1})
$N_0(0)$	= $N(0)$ value at zero altitude	
ρ	= Air density	(kg/m^3)
ρ_0	= Air density at zero altitude	(kg/m^3)
P_1, P_2	= PSD gust occurrence parameters; time fractions that non-storm turbulence and storm turbulence occur	
S	= Wing area	(m^2)
V	= True airspeed	(m/s)
U_{de}	= Derived gust velocity	(m/s EAS)
U_σ	= PSD-gust velocity	(m/s EAS)
V_E	= Equivalent airspeed, $V * \sqrt{\frac{\rho}{\rho_0}}$	

EXECUTIVE SUMMARY

Existing European data sources on acceleration experience in commercial aircraft were acquired and combined into one data base. The acceleration peak/valley data were reduced to discrete gust velocities and related gust velocities. The data were further analysed to yield gust intensity parameters. The present report gives an overview of the different data sources and the format in which they were made available. The data reduction procedures are described and the results are presented both in tabular and graphical format. The resulting gust statistics are compared with existing models.

1. INTRODUCTION.

The Federal Aviation Administration (FAA) and the Netherlands Civil Aviation Department (RLD) have signed a Memorandum of agreement (MOA) in the area of aircraft structural integrity with specific reference to aging aircraft. As part of this MOA, the National Aerospace Laboratory (NLR) was contracted to participate in the Flight Loads Program that has been defined and is carried out by the FAA. The main task of NLR in this program was defined as follows:

- Identification and acquisition of existing European Flight Load Data Sources.

- Definition of a unified procedure to reduce acquired acceleration data toward gust statistics.

- Reduction of the acquired data and reporting of the results.

Three following data bases containing information about center of gravity (c.g.) vertical acceleration experience of commercial transport aircraft were identified and acquired for analysis:

- A very large data base containing data on c.g. acceleration peaks and valleys with $|\Delta n_z| \Rightarrow 0.5$ pertaining to 838,657 flights made by different aircraft operated by British Airways. This data base was kept at office National d'etudes et de recherches aerospatiales (ONERA) and was acquired from that institute for the present investigation. This data base will be further indicated as ONERA data base.

- A data base kept at NLR containing detailed information about the aircraft flight profiles and acceleration peaks $|\Delta n_z| \Rightarrow 0.18$, referring to 24,358 flights made by Boeing B-747 aircraft operated by KLM, SAS and Swissair. The data were extracted from the Aircraft Condition Monitoring System (ACMS) data, and this data source will be further indicated as ACMS data base.

- A data base collected by several years ago by the Royal Aircraft Establishment (RAE), containing Fatiguemeter data in a wide variety of mainly piston-engined aircraft. This data base which includes 10,697 flights will be further indicated as Fatiguemeter data base.

In reference 1, a unified procedure to reduce these c.g. acceleration data towards gust statistics was defined. This procedure includes two methods: (a) reduction using a "discrete gust approach" and (b) reduction on the basis of a "continuous" or PSD-gust approach. The discrete approach makes use of the well-known "Pratt formula" to reduce Δn_z values to "derived gust velocities" U_{de}. It may be recalled that the Pratt formula is based on the assumption of a discrete gust with (1-cos) shape and a length of 25 wing chords and an aircraft that is infinitely stiff and responding only in plunge (no pitch). The "PSD" approach reduces recorded Δn_z peaks/valleys to U_σ values. The method is based on a continuous-gust concept and a simplified expression for the aircraft response including both pitch and plunge as proposed by Dr. Houbolt (see reference 2). Also, the so-called N(O) effect is taken into account.

The present report starts with an overview and description of the three different data bases. Chapter 3 describes the reduction of the data and presents the results obtained for the three different data sets. In chapter 4, the three sets are compared and where applicable the data are merged to obtain one overall statistical base for U_{de} and U_σ respectively. Also, from the U_σ-exceedance curves obtained for the various altitude bands "best fit" P_1, P_2 and b_1, b_2, values pertaining to the well-known PSD-turbulence intensity model are derived. Chapter 5 is devoted to an overall discussion of the results obtained and a comparison with existing gust statistics. The report ends with conclusions and recommendations.

2. REVIEW OF DATA BASES.

2.1 ONERA DATA BASE.

This data base contains information about all c.g. acceleration peaks/valleys larger than $|\Delta n_z|=0.5$ that occurred in a batch of 838,657 flights. These data were gathered by British Airways over a period of 10 years during normal operation of a variety of aircraft types and with the collaboration of the British Civil Aviation Authority (CAA), made available to the ONERA for statistical analysis. Table 1 provides a general overview of the flights contained in the data base. This data base was provided by ONERA to the NLR for the present study on magnetic tape in a format as shown in table 2. Each line in this table, to be called "Record", refers to one specific peak or valley in the data base. In the context of the present study, it is useful to note that for each peak/valley, apart from the Δn_z value, the aircraft mass, speed, altitude and $C_{L\alpha}$-value, at the instant of the peak occurrence, are provided. The peaks and valleys included in the data base were recognized using the so-called peak-between-means criterion, which states that between two crossings of the (n_z=1)–level only one peak or one valley can be classified.

Table 2 includes a column "idur", described as "duration of acceleration peak". This duration is actually the duration of the turbulence patch in which the particular peak/valley occurred (i.e., duration of the period in which accelerations in excess of $|\Delta n_z|=0.4$ were observed). As shown in table 2, these patches may last from a few seconds to several minutes. If more than one peak/valley were classified during one patch, the data base presented the additional aircraft data for the first peak only. The same additional aircraft values apply to the following peaks in the turbulence patch and are defined as zero in the data base (table 2).

The data received from ONERA were first subjected to a quality check, with specific reference to the presence of highly improbable data or missing data. From the total number of 10,648 records pertaining to peaks/valleys larger than $|\Delta n_z|>0.5$, sixty-six had to be rejected. For forty-nine of these, data for either mass m, speed V, altitude h, $C_{L\alpha}$ or Δn_z were missing and for the remaining seventeen, either unrealistically high or low values for $C_{L\alpha}$ or V were recorded.

Table 3 presents a complete overview of all acceleration peaks/valleys in the data base as a function of altitude range.[1)] The load factor exceedance curve per flight is presented in figure 1.

During the last two years of data accumulation for the Boeing B-747, positive load factor peaks between Δn_z=0.3 and 0.5 were also accumulated. Because these additional data were available for a limited number of flights and only for positive peaks, they were unsuitable for the data analysis performed in the present study and hence deleted from the data base. For completeness, the acceleration data including the above mentioned peaks between Δn_z=0.3 and Δn_z=0.5 referring two years of B-747 measurements are provided in table 4. The associated load factor exceedance curve is depicted in figure 2.

[1)] The altitude bands defined for the present study are given in appendix A

2.2 THE ACMS DATA BASE.

During a period of about ten years, service load data had been retrieved from ACMS recordings made in Boeing B-747 aircraft operated by the KSSU group (KIM, Swissair and SAS). These data were stored at NLR in the so-called ACMS Fatigue data base. A full description of this data base and the procedures followed for its creation has been presented in reference 4. The following is a brief description of the ACMS data base structure.

The ACMS data base contains data that are relevant with regard to aircraft usage and aircraft load experience. The data are stored on a flight-by-flight basis and include:

- General flight data: Date, departure and arrival airport, type of flight, take off weight are kept.

- Mission profile data: Each flight is divided into a number of successive flight segments. For each flight segment the following data are kept: Time, speed, altitude, Mach number, and aircraft weight at the beginning of the segment.

- Acceleration peak data: The c.g. acceleration trace included in the original ACMS data has been searched for peaks and valleys; whereby a range-filter of dn=0.18 was maintained (recognized successive peaks and valleys differ at least 0.18g). The values of the successive peaks and valleys are stored in the data base, together with the following information:

    - Time at occurrence of peak/valley.
    - Flap position.
    - Bank angle (for a limited number of recorded flights only).

In the context of the present study, it is interesting to note that from the data stored, the weight, speed, and altitude at the instant of a peak/valley occurrence can be determined by interpolation from the mission profile data. Also, it is useful to note that the mission profile data contained sufficient information to calculate total time and distance flown within different altitude bands.

Table 5 provides an overview of the flights contained in the ACMS data base, including a distribution of flight durations. Note that the ACMS data base includes 24,358 flights and a total number of 121,894 flight hours (airborne time).

Table 6 presents a distribution of time spent and distance flown within the different altitude bands. For the present study, the acceleration peaks/valleys contained in the original ACMS data base were first "filtered" according to the "peak-between-means" criterion. The resulting data base appeared to contain a number of improbably high positive acceleration peaks, sometimes with a value Δn_z well above Δn_z=1.00. These high peaks were further analyzed; whereby the required C_L to obtain the recorded Δn_z-value was determined and the peak/valleys occurring at about the same time in that flight were reviewed. Acceleration peaks above $|\Delta n_z|$=1.1 occurring in isolation (evidently not within a batch of heavy turbulence) sometimes requiring C_L-values well above $C_{L_{max}}$, were either considered max as "spikes" or as isolated maneuvers and deleted. Consequently twenty acceleration peaks were removed from the data base.

Table 7 gives an overview of the remaining peaks/valleys as a function of altitude band. The c.g. acceleration peak/valley exceedance curve per flight is presented in figure 3.

2.3 FATIGUEMETER DATA BASE.

During the fifties and early sixties, the United Kingdom collected a considerable amount of counting accelerometer data from a large number of different aircraft types. The data consisted of acceleration counter readings with speed and altitude, read out every ten minutes during flight. The Royal Aircraft Establishment (RAE) operated and maintained this specific data base. This data base was put on magnetic tape and was made available to all nations participating in a Working Group on Environmental Statistical Data of the Advisory Group for Aerospace Research and Development (AGARD) Structures and Materials Panel. Reference 5 presents an overview and analysis of these data. Unfortunately, the original data base was no longer available at RAE, but the magnetic tapes with the data that had been acquired by the Netherlands as a participant of the AGARD working group was available at NLR and the data was still reasonably readable. The data presented and analyzed in the present study have been obtained from these tapes.

Table 8 provides a general overview of the aircraft types involved and the number of flight hours and distances covered. Compared to the ONERA and ACMS bases, the Fatiguemeter data base is obviously relatively small. However, many of the data refer to piston-engined aircraft, some of them cruising at relatively very low altitude. The dearth of low altitude turbulence data was considered sufficient reason to include these data in the present study.

The format in which the data were grouped and presented on the magnetic tape is as follows:

- Data were presented separately for each aircraft type included.

- Data per aircraft started with a header file providing the aircraft type, the total flight time, distance flown, and data collection period.

- A number of "classes" pertaining to the specific aircraft were defined for the following variables:

  - Airspeed, altitude, weight, and flight condition.
  - Acceleration.

  Table 9 gives as an example the header and class definition for the Boeing B-707.

- The acceleration data were grouped in separate "records", each record referring to one combination of weight, altitude, and speed. Information in each record includes:

  - Time spent and distance covered.
  - Number of acceleration level crossings within each defined acceleration class.

Reference I describes the operation of the "Fatiguemeters" that were used to obtain the counting accelerometer data. In addition, the method used in the present study to "translate" the acceleration level crossings into acceleration peaks and valleys is described in reference 1. Table 10 summarizes the conversion from level crossings to peaks/valleys. The Fatiguemeter data were grouped in altitude bands that differed from aircraft to aircraft and did not correspond with the altitude bands maintained in this study. Conversion of the Fatiguemeter data to the present altitude band was carried out by linear interpolation. Table 11 gives an overview of all peaks/valleys pertaining to the Fatiguemeter data base. The Fatiguemeter data base did not contain information about the number of flights. However, using the route lengths for the various aircraft types given in reference 5, table CT1, and the distances flown in tables CT2 up to CT29, average numbers of flights were estimated. The resulting peak/valley exceedance curve per flight is presented in figure 4.

Acceleration data are presented per "record"; thus, each record refers to one specific aircraft type and one mass/altitude/speed bracket. The accelerations can then be reduced to "gust velocities" using the average mass, altitude, and speed pertaining to the particular bracket. However, looking at table 9, which is typical for all aircraft included in the Fatiguemeter data base, the brackets for mass, speed, and altitude are fairly wide; consequently, the accuracy of derived gust velocities is limited and considerably less that either the ONEPA or ACMS data bases.

2.4 DATA BASE COMPATIBILITY.

The three data bases described in the previous sections were obtained using different techniques, over different periods, and largely from very different aircraft. In order to combine the gust statistics derived from these data bases into one gust data base, it was felt useful to perform an elementary check on the overall compatibility of the acceleration data. It is generally accepted that load factor spectra per flight for transport aircraft tend to show considerable resemblance, independent of flight duration and aircraft type (see reference 6). Figure 5 shows load spectra per flight pertaining to the three different data bases. The spectra for the ACMS data and the ONERA data show a remarkably good agreement, but the spectrum derived from the Fatiguemeter data is about an order of magnitude more severe. The ONERA base includes different aircraft types; whereas the ACMS base includes only B-747 aircraft. If one compares the ACMS spectrum with the ONERA spectrum for to B-747s only, the agreement is even slightly better, see figure 6. From figure 6, the load factor spectrum per flight for the B-747 is approximately the same as the average load spectrum per flight for all aircraft included in the ONERA data base. With regard to the Fatiguemeter data, one must consider that these data were obtained in a much earlier period when weather predictions were less accurate, resulting in more frequent turbulence encounters and consequently more severe load spectra. More important, however, is that the Fatiguemeters were largely installed on piston-engined aircraft which cruise at lower altitude where more turbulence is encountered. Table 12 shows the distribution of flight distances over the different altitude bands for the three data sets, indicating that more than fifty percent of the Fatiguemeter data were collected at altitudes between 4,500 and 19,500 ft compared to approximately ten percent and four percent for the other two data sets. Table 13 gives the exceedance frequencies per flight for Δn_z=0.3 and Δn_z=0.6 for the different aircraft of the Fatiguemeter data base as well as for ONERA and ACMS data as a whole. The batches per aircraft type in the Fatiguemeter data base are pretty small, so one must be careful in drawing conclusions from such limited information. Note, however, that the figures for the Boeing B-707, which is the only aircraft comparable with types included in the ONERA and ACMS base with regard to wing load and cruising altitude are comparable with ONERA and ACMS values. The high load factor experience of the Comet 1 as indicated in table 13 is perhaps somewhat surprising but it must be realized that the Comet 1, although a "pure jet", had a relatively low wing loading (see table 14) with associated relatively high gust sensitivity. Finally, note that the Bristol Freighter is a major contributor to the overall exceedance figures of the Fatiguemeter data base. The high load factor experience of this low wing load transport aircraft with very short "hops", e.g. over the English Channel, is not surprising. In summary, one may conclude that the ACMS data and ONERA data appear very compatible. The Fatiguemeter data obviously pertain to a different era and a different generation of aircraft. The comparisons made above, however, give no reason to doubt the validity of these Fatiguemeter data.

3. REDUCTION OF ACCELERATION DATA.

As explained in the previous chapter, the three data bases consist essentially of a collection of acceleration peaks and valleys. Apart from the type of aircraft, for each acceleration peak or valley, the speed; altitude; and aircraft mass at the instant of acceleration peak occurrence are available (can be derived from available data) with a degree of accuracy that depends on the data base and is smallest for the Fatiguemeter data. The procedures to reduce these acceleration peak data to derived gust velocities U_{de} and U_σ have been established in full detail in reference 1. The essential elements of the reduction procedure may be summarized as follows:

U_{de}: Reduction on the basis of a "discrete" gust concept. U_{de} is calculated with the well known Pratt formula. This implies that a [1-cos]-shaped gust with 25 chords length and an aircraft response in heave only is assumed. Each Δn_z-peak/valley results in one discrete gust with speed U_{de}.

U_σ: Reduction on the basis of a "continuous" gust concept. U_σ is calculated using a simplified formula derived by John Houbolt and presented in reference 2. The formula is based on a PSD gust model with "von Karman" spectrum, and aircraft response in pitch and heave. Variation of N(O) as a function of aircraft response properties is accounted for by reducing each acceleration peak to $N(O)_{ref}/N(O)$ "gusts". Again, for N(O) an expression is used which was derived by John Houbolt.

The equations used in the reduction procedure are summarized in appendix A.

Grouping the derived gust velocities according to altitude results in overall gust exceedance data for each altitude band in each data base. In order to reduce these overall exceedance data to exceedance figures "per unit distance", these figures must be divided by the total distance flown in each altitude band for all flights contained in the specific data base. In the following subchapters, the reduction performed for each of the three different bases will be reviewed, specific problems encountered are discussed, and the results obtained will be presented.

3.1 ONERA DATA BASE.

Table 14 presents the geometric data for the aircraft models included in the ONERA data base. This data, together with the data in each peak/valley record on instantaneous mass, altitude, speed, and $C_{L\alpha}$ are sufficient to allow reduction of each acceleration peak/valley to gust velocities U_{de} and U_σ. The resulting "overall" gust exceedance data are presented in the tables 15 and 16. The ONERA data base does not include direct information about the distances flown within the various altitude bands but only presents total number of flight hours and total "block" time per aircraft type. Reference 7 contains information provided by British Airways about the average time per flight spent in taxi, takeoff, and roll out. Using this information, average airborne flight durations for each aircraft were estimated, see table 17. From the peak/valley data records, average speeds for each aircraft type within each altitude band were calculated. Using this data, estimating climb and descent speeds and using the limited mission profile information from reference 7, mean flight profiles were estimated. The result is presented in table 18. Using data from this table along with the total number of flights per aircraft type, the total distance flown in each altitude band can be estimated. The, result is presented in table 12. Using these figures, the "overall" exceedance data can be converted to "exceedances per Kilometer" for each altitude band. U_{de} values for four altitude bands are presented in figure 7. The "lower boundary" $|\Delta n_z|$=0.5 corresponds with different U_{de} values, depending on aircraft weight, speed, etc., but below values of approximately $|U_{de}|$=7 m/s the curves drop off, indicating that below that U_{de} value the curves have no statistical significance. Note that for all altitudes, except for the very low altitude bands, the curves are remarkably symmetrical, indicating that the original Δn_z data contained little contributions due from maneuvers. As expected, the frequency of exceedance of the same gust velocity decreases with increasing altitude. This is also illustrated in figure 8, where the exceedance frequency of specific gust velocities as a function of altitude are presented. At very low altitude the exceedance frequency drops off again. However, as will be discussed in the next chapter, the ONERA data in the altitude range below 4,500 feet appears improbably light compared to the other two data sources. The U_σ data show the same trend and is not presented here. The lower boundary for valid U_σ data is in the order of $|U_\sigma|$=11 m/s for lower altitudes and 8 m/s for high altitudes.

3.2 ACMS DATA BASE.

For each acceleration peak/valley and instantaneous mass, speed and altitude are contained in the data base. Geometric data of the B-747 aircraft involved are presented in table 14. The $C_{L\alpha}$-values has been calculated using the equations presented in reference 8 and reproduced in appendix B. The "overall" exceedance data per altitude band for U_{de} and U_σ are included in the tables 19 and 20 respectively. The ACMS data base includes complete information about the distances flown in each altitude band, see table 6. Hence, "overall" exceedance data can be directly converted to "exceedings per kilometer". Results for U_{de} for the four different altitude bands are presented in figure 9. Note that because of the much lower "boundary value" $|\Delta n_z|$=0.18 compared to the ONERA data, the lower bound for significant U_{de} values is considerably lower, i.e., 3 m/s for U_{de} and 5m/s for U_σ. On the other hand, due to the much smaller batch size the upper boundary for significant U_{de} data is about 10 m/s.

3.3 FATIGUEMETER DATA BASE.

As explained in chapter 2, the acceleration peaks/valleys are available per mass/speed/altitude bracket for each aircraft. The geometric data of the different aircraft are given in table 14. $C_{L\alpha}$ values for the aircraft in the Fatiguemeter data base were not available and have been approximated according to:

$$C_{L\alpha} = 1.15 * 6A/(A + 2)$$

where A is the aspect ratio. The derived "overall" exceedance data per altitude band for U_{de} and U_σ are presented in the tables 21 and 22 respectively. Each "record" in the Fatiguemeter data base contains the distance covered for one aircraft and one speed/mass/altitude bracket. Summation over all aircraft and all mass and speed brackets gives the total distance within each altitude bracket. Conversion of these data "per Fatiguemeter Altitude Bracket" towards the altitude bands maintained in the present study were performed by linear interpolation. The result is included in table 12. Exceedance curves for U_{de} pertaining to four altitude bands have been plotted in figure 10. The "lower boundary" for valid U_{de} values is in the order of 2 m/s, hence slightly lower than for the ACMS data, but due to the relatively very small batch size, the "upper boundary" for valid U_{de} values is limited in the higher altitude bands to about 6 or 7 m/s.

In general, the U_{de} exceedance values derived from the Fatiguemeter data are considerably higher than those pertaining to the ACMS data. Figure 11 shows that exceedance frequencies for the same U_{de} are about 10 times higher for the Fatiguemeter data than for the ACMS data.

4. DEVELOPMENT OF STATISTICAL GUST MODELS.

The previous chapter described the reduction of the c.g. acceleration data to "gust" data for the three different data bases. The ONERA data refer to a very large number of flights and very many kilometers travelled, but that, because of the restriction to $|\Delta n_z|>0.5$, the derived gust data of relevance are restricted to gust velocities in the order of $|U_{de}|>7$ m/s or $|U_\sigma|>8\text{-}11$ m/s. The ACMS data give valid data for much lower $|U_{de}|$ values, 3m/s, ($U_\sigma>5$ m/s), but due to the much smaller batch size, the statistical relevance of the ACMS data is restricted to U_{de} values below 10 m/s ($U_\sigma<$ 13 m/s).

The main objective of the present study is to <u>combine</u> the data of the different data sets into one unified "Discrete Gust Statistical Model" and to redetermine P_1,P_2 and b_1,b_2 values related to the PSD-gust model. The procedure followed in the present study for merging the respective data sets will be generally described for the case of the U_{de} statistics.

For each altitude band, the U_{de} exeedance data on a "per kilometer" basis pertaining to the three data bases are plotted in one figure. A typical example, relating to the altitude band from 34,500 to 39,500 feet, is shown in figure 12. The first observation to be made from these plots was that for all altitudes except the very lowest altitude bands the exceedance frequencies for the Fatiguemeter data were nearly an order higher than the figures from the ONERA and ACMS data. This fact was already documented in figure 11 where exceedance frequencies of two gust velocities pertaining to the ACMS data and the Fatiguemeter data respectively are plotted. A probable cause for this difference is the fact that the Fatiguemeter data come from considerably different aircraft operated in a different era when weather predictions and thus the means to avoid turbulence were considerably less effective. Since we are primarily interested in gust statistics that are relevant for current and future operations, and considering that the Fatiguemeter database is relatively small and has limited accuracy, it was decided not to include the Fatiguemeter data in the "combined" data set, except for the lowest altitude band. Returning to figure 12, one may observe that the curves pertaining to the ONERA and ACMS data can be fitted relatively easily into one smooth curve for both the upward and downward gusts. This was the case for most altitude bands except for a few cases like the one shown in figure 13 where, although the slope of the ACMS data and ONERA data were in good accordance, the curves did not line up. For the ONERA data the number of kilometers in each altitude band were derived on the basis of estimated mission profiles; hence, these figures may be somewhat inaccurate. On the basis of this consideration it was decided to obtain a smooth curve by a small shift of the ONERA curve towards the right. This means that it is assumed that the actual number of kilometers flown in the considered altitude band is less than originally estimated. For the lowest altitude band, the ONERA data appears improbably low and rather inconclusive, see figure 14. The reason for this apparent lack of representativeness could not be traced back but may have been related to some unknown restriction on data recording, e.g., in flap-out conditions. To maintain a certain amount of conservatism, it was decided to generate the "combined" data set for the lowest altitude band from a combination of the ACMS data and the Fatiguemeter data. From the smoothed "combined" exceedance curves for both upward and downward gusts, "onesided" exceedance curves were derived by taking the geometric mean of the exceedance frequencies of the positive and negative gust velocities:

$$N\langle|U_{de}|\rangle = \sqrt{\{N(U_{de}+) * (U_{de}-)\}}$$

The resulting curves are plotted in the figures 15a and 15b and are presented in tabular form on table 23. The same procedure as described above with regard to U_{de} was used to obtain "combined" and one-sided exceedance curves for U_σ. The $|U_\sigma|$ curves obtained were used to estimate P_1,P_2 and b_1,b_2 values to be applied in the PSD-gust model. The method used is illustrated in figure 16 and may be described as finding the -"best fit" approximation of the $|U_\sigma|$ curve by the sum of two straight lines in a semi-logarithmic grid. The resulting figures have been presented in tabular form on table 24. Note that P_2 and b_2 values could not be determined for the lowest altitude band (below 1,500 ft) and the highest altitude band (above 39,500 ft). Note: The parameter values P_1,P_2 and b_1,b_2 define an U_σ exceedance curve of the form:

$$N\ (|U_\sigma|) = N\ (0) * \{P_1 * e^{-U_\sigma./b_1} + P_2 * e^{-U_\sigma/b_2}\} \qquad (4.1)$$

Figure 17 shows, as an example, for the altitude band between 24,500 and 29,500 feet, the "original" combined U_σ exceedance curve and the "fitted" curve according to the above expression, illustrating the "goodness of fit" obtained. U_σ curves calculated from equation 4.1 for the various altitude bands are presented in figures 18 and 19. The associated U_σ exceedance values are presented in table 25. Note that the $|U_\sigma|$ statistics presented refer to a reference N(O) value equal to

$$N(0)_{ref} = N_0(0)_{ref}\ x\left(\frac{\rho}{\rho_0}\right)^{.46} \quad \text{and} \quad N_0(0)_{ref} = 8\ \text{km}^{-1}$$

5. DISCUSSION.

In this report, an attempt has been made to establish improved U_{de} exceedance data and improved values for the PSD related parameters P_1,P_2 and b_1,b_2 on the basis of VGH type data available from European data sources. The improvement in comparison with existing descriptions is expected to be due to (a) the size of the available data batch, (b) the quality and resolution of the data, (c) the analysis techniques applied and, (d) the time period of the data recordings. The size of the present data batch, 1.6 billion kilometers and 2 million flight hours, is really impressive compared data available from other sources. For example, according to reference 9 the total sample size of data collected by NACA/NASA between 1947 and 1965 amounted to 42,000 hours VGH data and 507,000 hours of VG data. The data presented in the Engineering Science Data Unit (ESDU) sheets, reference 10, are based on 12 million kms in "cruise" and 4 million kms in "climb and descent". At an average air speed of 500 km/hour, about 32,000 flight hours were collected. In 1971, a relatively large data base (including the Fatiguemeter data covered in the present study) of about 152,000 flight hours was made available through an AGARD effort. These data were only reduced for PSD statistics and presented "per aircraft" only, see reference 11. With regard to the quality and resolution of the present data, there is no doubt that both the ACMS data as well as ONERA data were obtained with higher resolution and, for various parameters like weight, with a higher accuracy than other previous data bases investigated. With regard to the analysis technique applied, it is felt that specifically the reduction formula used for deriving U_σ values is an improvement compared to previous derivations whereby an $\bar{A}$ value was calculated assuming heave response freedom only. See reference 12. Finally, note that the present data largely refer to relatively recent operations with many aircraft models still in service. It has been observed already that because of less effective turbulence avoidance possibilities, older data tend to reflect a more severe turbulence environment than more recently collected aircraft operation data.

It is interesting to compare the presently derived gust statistics with older descriptions. Figure 20 compares exceedance frequencies of specific U_{de} gust velocities as a function of altitude from NACA TN4332, reference 12, resulting from the present analysis. For the lowest altitude band the current results are more severe, especially for higher gust velocities. The difference gets rapidly smaller with increasing altitude and at higher altitude the present data have a considerably lower exceedance frequency. Figures 21 and 22 show a comparison of P-values and b-values for the PSD model as derived in the present study and as described in the Airworthiness Requirements FAR25 and Appendix G (also- ACJ25.305) respectively. (For convenience, b-values presented in figure 22 are given as "TAS" values.) It is noted that the presently derived P-values are generally lower for all altitudes. For altitudes above 10,000 feet, the "non-storm" component P_1 is about ten times lower and the "storm" component P_2 from two to six times lower. The intensity parameter for "non-storm" conditions, b_1, on the other hand, is approximately 1.5 times larger, while b_2 is about 10 percent lower than given in FAR25. In summary, the present data indicate that light turbulence is encountered considerably less frequently but that the intensity of such turbulence tends to be somewhat higher. Severe turbulence is encountered less frequently, and has a lower intensity than according to FAR25.

Despite the large size of the present data set, it should be noted that the information obtained has its limitations. For example, data for altitudes above 39,500 feet are scarce and probably unreliable. It should be realized that the data for these high altitude are severely biased; for most aircraft 40,000 feet is close to their ceiling, especially in heavy aircraft configuration. To avoid stall problems, aircraft flying very high reduce altitude when turbulence is expected, and hence recordings show little turbulence at these high altitudes. Also, data for the lowest altitude range in the present data set may contain a considerable amount of low altitude maneuvers which could not be identified and removed prior to the gust analysis.

Finally, it must be realized that the method followed to derive the PSD-gust intensity parameters P_1,P_2 and b_1,b_2 from the U_σ exceedance curves is an indirect procedure and, although generally applied in the past, theoretically not fully correct.

As part of the FAA Aging Aircraft Research Program, an extensive Flight Load data acquisition program is being developed, whereby in a number of US civil transport aircraft will be instrumented and a large number of flight load parameters will be continuously recorded. These recordings will present a considerable amount of statistical data on aspects like control surface usage and loading but equally important will offer the opportunity to extend our data base on gust experience at a very fast rate. In particular, the load experience at low altitude can be determined with considerably more accuracy than in our present study because from the continuous loads records due to gusts and due to (banking) maneuvers can be separated. In addition, the continuous data offers the opportunity to determine the intensity parameters of the PSD-gust model in a more direct way. The procedure to be followed for this purpose can be described as follows: (a) From the continuous airplane parameter time history record, calculate the "instantaneous" RMS value for Δn_z, $\sigma(\Delta n_z)$ record. (b) Calculate the instantaneous value of $\bar{A}$. (c) Calculate the instantaneous value of $\sigma(w)$ as $\sigma(w)=\sigma(\Delta n_z)/\bar{A}$. (d) Determine values for $P_1, P_2,$ and b_1, b_2 that give "best fit" to the empirical $\sigma(w)$ probability function tabulated from instantaneous $\sigma(w)$ values.

6. SUMMARY AND CONCLUSIONS.

1. Available European data sources on center of gravity acceleration experience in commercial aircraft have been analysed and combined into one data base.

2. This data base includes about 870,000 flights, 2 million flight hours, and 1.6 billion kilometers flown.

3. Acceleration peak data were reduced towards discrete gust velocities U_{de} and PSD related gust velocities (U_σ).

4. PSD-gust velocity exceedance data were further reduced to yield PSD-gust intensity parameter values ($P_1, P_2,$ b_1, b_2).

5. The results obtained show a considerably lower gust experience at higher altitude than predicted by currently used statistical models. At low altitudes, current data tend to confirm the older statistical data.

6. Data about gust experience at low altitude (below 2,000 feet) are still incomplete and biased by maneuver induced accelerations.

7. The planned FAA flight load measurements for US commercial transport aircraft will provide additional and missing information and offer the opportunity to get better information on PSD-gust intensity distributions.

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TABLE 1. OVERVIEW OF ONERA FLIGHT LOAD DATA

Aircraft type	(1) Flights	Flight hours	Period of recording	(1) Mean flight duration	(2) Total of pos. peaks	Total(2) of neg. peaks
Trident 1	6805	4760	1980-1982			
Trident 2	25875	23297	1980-1985			
Trident 3	105012	88656	1980-1986			
All Trident	137692	116713	1980-1986	0.85	162	150
Bac 1-11	132495	102500	1980-1986	0.77	1172	802
Tristar 1	21790	37844	1980-1985			
Tristar 100	8102	25612	1980-1984			
Tristar 200	20662	66865	1980-1985			
Tristar 500	26335	47583	1980-1985			
All Tristar	76889	177904	1980-1985	2.31	665	565
B-747-136	106849	522439	1980-1990			
B-747-236	80007	488449	1980-1990			
All B-747	186856	1010888	1980-1990	5.41	1431	1315
B-737	274511	326591	1980-1988	1.19	1518	1483
B-757(1)	4819	10354	1981-1985			
B-757(2)	25395	36598	1983-1985			
All B-757	30214	46952	1981-1985	1.55	654	665
All aircraft	838657	1781548	1980-1990	2.12	5602	4980

Notes: Flight hours and flight duration
(1) refer to the block time.
(2) valid peaks/troughs with $|\Delta n_z|$=>0.5 in data base.

TABLE 2. FORMAT OF PEAK/VALLEY INFORMATION IN ONERA DATA BASE

ity	in	ic	is		dep	arr	mass	kias	ktas	kalt	iv	il	idur		M	Cla	dNz+	dNz-	nm	ns	nj
2	6	0	7		1LHR	1HEL	50280	296	336	8390	0	0	10		0.508	4.224	0.00	0.63	4	16	105
2	6	0	7		1LHR	1ARN	49380	284	429	25710	0	0	12		0.677	4.562	0.52	0.00	6	23	158
2	7	0	7		1LHR	1GVA	43360	266	299	7680	0	0	157		0.452	4.283	0.52	0.00	4	18	121
2	7	0	7		0	0	0	0	0	0	0	0	0		0.000	0.000	0.00	0.70	0	0	0
2	7	0	7		0	0	0	0	0	0	0	0	0		0.000	0.000	0.63	0.00	0	0	0
2	7	0	7		1LHR	1INV	43600	278	295	4100	0	0	65		0.443	4.230	0.52	0.00	9	38	262
2	8	0	3		1LHR	1ZAG	52480	268	509	37160	0	0	30		0.805	5.221	0.00	0.55	4	15	99
2	8	0	2		1ZAG	1LHR	53330	276	355	16220	0	0	5		0.548	4.348	0.00	0.59	4	15	99
2	8	0	2		1SNN	1LHR	48710	285	310	5590	0	0	15		0.467	4.222	0.51	0.00	5	21	146
2	9	0	7		1LHR	1INV	48730	326	374	9000	0	0	38		0.564	4.162	0.51	0.00	2	6	35
2	9	0	2		1BCN	1LHR	56050	281	299	4150	0	0	28		0.449	4.222	0.61	0.00	6	24	163
2	10	0	8		1LHR	1GVA	47096	220	240	5900	0	1	1		0.369	4.379	0.52	0.00	9	36	248
2	10	0	2		1MAN	1LHR	47750	273	302	6780	0	0	70		0.457	4.258	0.55	0.00	9	37	258
2	11	0	7		1LHR	1HEL	47096	352	396	7730	0	0	62		0.608	4.121	0.51	0.00	1	2	12
2	11	0	7		1HAM	1LHR	48750	340	480	21830	0	0	70		0.740	4.515	0.73	0.00	8	33	224
2	11	0	2		1LHR	1BUD	47456	271	286	3650	0	0	5		0.437	4.254	0.55	0.00	12	52	361
2	13	0	7		1LHR	1GLA	44040	289	352	12880	0	0	10		0.540	4.289	0.53	0.00	6	23	158
2	13	0	5		1MAN	1LHR	47450	225	258	9040	0	1	10		0.393	4.386	0.58	0.00	6	24	166
2	14	0	7		1LIS	1LHR	48190	319	424	18190	0	0	2		0.652	4.338	0.51	0.00	6	24	162
2	14	0	3		1IST	1LHR	53860	314	527	31280	0	0	17		0.824	5.106	0.52	0.00	6	25	173
2	14	0	7		1LHR	1ABZ	46900	355	427	12040	0	0	10		0.646	4.171	0.60	0.00	9	38	262
2	16	0	7		1LHR	1HAM	50410	320	408	15660	0	0	4		0.627	4.285	0.57	0.00	4	14	94

ity: type of aircraft
in: aircraft number
ic: 0 acc. due to turbulence
1 acc. due to maneuvers
is: flight mode
ep: code for departure airport
arr: code for arrival airport

mass: aircraft mass in kg
kias: indicated airspeed (knots)
ktas: true airspeed (knots)
kalt: flight altitude (feet)
iv: flap position (degrees)
il: leading edge flaps (in/out)
idur: duration of acc. peak

M: Mach Number
Cla: lift curve slope
dNz+: pos. incr. load factor
dNz-: neg. incr. load factor
nm: month since beginning data
ns: week since beginning data
nj: days since beginning data

TABLE 3. ONERA DATA BASE—OVERVIEW OF ACCELERATION PEAK DATA $|\Delta n_z|>0.5$

Total number of flights : 838657
Total flight hours : 1781548
The mean flight duration: 2.12 hours

Δn_z >	Altitude < 1500	1500 4500	4500 9500	9500 14500	14500 19500	19500 24500	24500 29500	29500 34500	34500 39500	> 39500	all alt
1.55	0	0	0	0	0	1	0	0	0	0	1
1.35	0	0	0	0	0	1	0	0	0	0	1
1.30	0	0	0	0	0	2	0	0	0	0	2
1.25	0	0	0	0	0	2	0	0	0	0	2
1.20	0	0	0	0	0	3	0	0	0	0	3
1.15	0	0	1	0	0	3	0	0	0	0	4
1.10	0	0	1	0	1	3	1	0	1	0	7
1.05	0	0	2	1	2	4	1	0	1	0	11
1.00	0	0	5	4	2	6	1	1	1	0	20
0.95	0	0	8	4	5	14	3	2	4	0	40
0.90	0	3	14	10	7	19	7	7	6	0	73
0.85	0	9	32	19	11	25	13	11	14	0	134
0.80	0	16	64	38	14	34	16	19	22	0	223
0.75	2	31	114	64	24	40	25	34	33	0	367
0.70	4	73	197	109	52	65	40	53	48	0	641
0.65	6	128	322	188	81	90	64	76	65	0	1020
0.60	8	293	671	370	161	162	148	171	125	0	2109
0.55	22	496	1155	622	263	267	253	303	227	1	3609
0.50	37	795	1778	925	421	386	391	497	371	1	5602
-0.50	50	551	1515	951	355	318	414	442	378	6	4980
-0.55	28	302	955	589	227	192	269	265	235	5	3067
-0.60	13	166	496	345	126	127	148	157	134	4	1716
-0.65	5	68	230	179	61	68	77	85	62	0	835
-0.70	1	46	144	120	44	49	53	58	45	0	560
-0.75	0	30	69	83	32	29	37	31	30	0	341
-0.80	0	15	38	44	24	19	22	15	22	0	199
-0.85	0	10	19	23	15	14	13	9	12	0	115
-0.90	0	8	9	14	5	11	9	6	9	0	71
-0.95	0	6	7	8	3	7	5	4	4	0	44
-1.00	0	4	3	5	3	6	1	2	3	0	27
-1.05	0	3	1	4	1	4	1	2	1	0	17
-1.10	0	3	0	1	1	3	0	1	0	0	9
-1.15	0	3	0	1	1	3	0	1	0	0	9
-1.20	0	2	0	1	0	2	0	1	0	0	6
-1.25	0	2	0	1	0	2	0	1	0	0	6
-1.30	0	1	0	1	0	1	0	0	0	0	3
-1.35	0	1	0	0	0	1	0	0	0	0	2
-1.60	0	1	0	0	0	1	0	0	0	0	2
-1.65	0	1	0	0	0	0	0	0	0	0	1

TABLE 4. ONERA DATA BASE—ACCELERATION DATA INCLUDING PEAKS $\Delta n_z > 0.3$

Total number of flights : 20505
Total flight hours : 142861
The mean flight duration: 6.97 hours

Δn_z >	Altitude < 1500	1500 4500	4500 9500	9500 14500	14500 19500	19500 24500	24500 29500	29500 34500	34500 39500	> 39500	all alt
0.95	0	0	0	0	0	0	0	0	1	0	1
0.90	0	0	0	0	0	0	0	1	1	0	2
0.85	0	0	0	0	0	0	0	1	1	0	2
0.80	0	0	0	0	0	0	0	1	2	0	3
0.75	0	0	0	1	0	0	1	4	3	0	9
0.70	0	0	0	1	0	0	1	4	3	0	9
0.65	0	0	0	5	1	0	1	4	4	0	15
0.60	0	2	0	5	2	2	3	6	10	0	30
0.55	0	2	1	13	2	4	6	11	19	0	58
0.50	0	6	7	25	9	6	15	26	38	0	132
0.45	0	11	27	43	21	9	33	41	64	0	249
0.40	2	29	67	82	39	24	65	89	132	0	529
0.35	3	53	139	140	74	45	121	167	221	1	964
0.30	11	90	264	210	128	67	179	341	414	1	1705
-0.50	0	4	11	26	7	2	11	21	27	0	109
-0.55	0	1	7	16	6	2	7	14	20	0	73
-0.60	0	1	5	11	5	2	4	10	16	0	54
-0.65	0	0	1	7	5	0	3	4	9	0	29
-0.70	0	0	0	3	3	0	1	3	7	0	17
-0.75	0	0	0	2	2	0	1	2	4	0	11
-0.80	0	0	0	2	1	0	1	2	2	0	8
-0.85	0	0	0	0	1	0	1	1	1	0	4
-0.90	0	0	0	0	1	0	0	1	1	0	3
-0.95	0	0	0	0	0	0	0	1	1	0	2

TABLE 5. OVERVIEW OF FLIGHTS CONTAINED IN ACMS DATA BASE

flight type legend	flight duration intervals {hrs}												all flight durations
	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-3.0	3.0-4.0	4.0-5.0	5.0-6.0	6.0-7.0	7.0-8.0	8.0-9.0	9.0-10.0	>10.0	
A	1591	1739	1110	1577	1347	1607	765	1651	4849	4696	1936	490	399	23757
B	9	43	28	55	90	43	26	4	17	15	22	10	0	362
C	0	1	2	0	0	0	0	0	0	0	0	0	0	3
D	1	4	3	10	7	10	0	0	1	0	0	0	0	36
X	23	37	6	11	22	8	4	4	39	24	17	5	0	200
all	1624	1824	1149	1653	1466	1668	795	1659	4906	4735	1975	505	399	24358

A = scheduled commercial
B = charter
C = test
D = training
X = miscellaneous

TABLE 6. ACMS DATA BASE—TIME AND DISTANCES WITHIN EACH ALTITUDE BAND

Altitude (ft)	Distance (km)	Time (hrs)
< 1500	366048	1228.2
1500 - 4500	972367	2582.0
4500 - 9500	1615754	3222.0
9500 - 14500	1760326	2756.0
14500 - 19500	1747858	2391.5
19500 -24500	2294179	2848.9
24500 - 29500	6340970	7178.9
29500 - 34500	37730084	41663.4
34500 - 39500	51915800	57626.9
> 39500	353491	395.6
all altitudes	105096877	121893.4

TABLE 7. ACMS DATA BASE—OVERVIEW OF ACCELERATION PEAK DATA

Total number of flights : 24358
Total flight hours : 121893.37
The mean flight duration: 5.00 hours

Δn_z >	Altitude < 1500	1500 4500	4500 9500	9500 14500	14500 19500	19500 24500	24500 29500	29500 34500	34500 39500	> 39500	all alt
1.30	0	0	0	0	0	0	0	1	0	0	1
1.20	0	0	0	0	0	0	0	1	0	0	1
1.15	0	0	0	0	0	0	0	2	0	0	2
1.00	0	0	0	0	0	0	0	2	0	0	2
0.95	0	0	0	0	1	0	0	2	0	0	3
0.90	0	0	0	0	1	0	0	4	0	0	5
0.85	1	0	1	0	1	0	0	4	2	0	9
0.80	1	0	3	2	3	0	0	5	2	0	16
0.75	1	0	5	4	3	4	1	5	2	0	25
0.70	1	1	7	7	3	7	4	7	9	0	46
0.65	2	5	8	12	7	13	9	14	15	0	85
0.60	4	7	15	15	16	17	11	28	23	0	136
0.55	9	9	23	26	23	22	19	46	42	0	219
0.50	25	21	55	47	31	40	32	79	80	0	410
0.45	57	67	111	85	59	64	57	129	132	1	762
0.40	117	177	238	161	85	97	90	215	255	2	1437
0.35	290	460	553	317	165	148	176	468	542	8	3127
0.30	848	1301	1258	665	332	257	355	1028	1154	24	7222
0.25	2717	4217	3204	1539	704	550	760	2365	2807	56	18919
0.20	9040	13143	8630	3670	1619	1217	1938	6314	7376	126	53073
0.15	28158	36906	21484	8126	3716	2829	4684	16661	18731	302	141597
0.00	28158	36906	21484	8126	3716	2829	4684	16661	18731	302	141597
0.00	11396	16785	11686	5800	3094	2302	3997	14831	16184	288	86363
-0.15	11396	16785	11686	5800	3094	2302	3997	14831	16184	288	86363
-0.20	2444	4291	4226	2280	1188	840	1509	5338	5962	101	28179
-0.25	624	1218	1566	945	511	348	636	2027	2273	44	10192
-0.30	224	390	636	457	222	147	297	806	971	16	4166
-0.35	77	187	272	241	114	67	151	403	459	9	1980
-0.40	39	115	128	128	53	38	78	198	232	2	1011
-0.45	25	88	74	69	30	29	47	111	139	2	614
-0.50	18	68	34	44	16	22	25	64	75	1	367
-0.55	14	51	20	26	12	18	15	42	48	0	246
-0.60	8	31	12	15	8	12	6	22	22	0	136
-0.65	6	27	6	9	6	6	4	8	13	0	85
-0.70	3	22	5	7	5	3	3	4	9	0	61
-0.75	1	16	3	4	4	2	2	1	6	0	39
-0.80	1	10	2	1	3	1	2	1	4	0	25
-0.85	1	6	1	1	3	0	1	0	2	0	15
-0.90	0	1	1	0	1	0	1	0	0	0	4
-0.95	0	0	0	0	1	0	1	0	0	0	2

TABLE 8. FATIGUEMETER DATA BASE—OVERVIEW OF DISTANCES AND FLIGHT HOURS

a/c type	Distance (km)	Time (hrs)
Ambassador	96178.0	892.58
B-707	526528.9	2231.34
Bristol	102274.3	1345.57
Brittania	196138.2	1227.84
Comet 1	329505.3	1807.19
Comet 4	257845.3	1184.56
Hermes 4	267898.3	2162.35
Hermes 4A	288230.7	2439.19
Stratocruiser	412900.5	3378.35
Constellation	488406.2	3765.94
Viking	124310.7	1324.27
Viscount	510443.3	3384.72

TABLE 9. FATIGUEMETER DATA BASE—EXAMPLE OF HEADER FILE

AIRCRAFT TYPE	BOEING 707
COUNTRY OF ORIGIN	GREAT BRITAIN
TOTAL TIME	2,231 HOURS
TOTAL DISTANCE	975,100 NAUTICAL MILES
GEOGRAPHY	EUROPE, AFRICA, TRANSATLANTIC, AUSTRALASIA, MIDDLE- AND FAR-EAST
DATE OF COLLECTION	1964-1965
INSTRUMENTATION	R.A.E. RECORDER
COUNTING METHOD	PRIMARY AND SECONDARY PEAKS
SYSTEM OF UNITS	FOOT-POUND-SECOND
ABARS	ONE-DEGREE-OF-FREEDOM

RANGE OF VALUES	ACCELERATION (G)	AIRSPEED (KEAS)	ALTITUDE (FT)	WEIGHT (LB)	FUEL (LB)
1		LESS	0	132250	N.A.
2	LESS	160	2000	154300	
3	-0.6 TO -0.4	180	4000	176350	
4	-0.4 TO -0.2	200	6000	198400	
5	-0.2 TO 0.0	220	8000	220450	
6	0.0 TO 0.2	240	10000	242500	
7	0.2 TO 0.4	260	14000	264550	
8	0.4 TO 0.6	280	18000	286600	
9	0.6 TO 0.7	300	22000	308650	
10	0.7 TO 0.8	320	30000		
11	1.2 TO 1.3	340	38000		
12	1.3 TO 1.4				
13	1.4 TO 1.6				
14	1.6 TO 1.8				
15	1.8 TO 2.0				
16	2.0 TO 2.2				
17	2.2 TO 2.4				
18	2.4 TO 2.6				
19	MORE				

FLIGHT CONDITIONS
1. INITIAL ASCENT
2. FINAL DESCENT
4. OTHER ASCENT
5. CRUISE
6. OTHER DESCENT

TABLE 10. FATIGUEMETER DATA BASE—CONVERSION OF LEVEL CROSSINGS TO PEAKS/VALLEYS

MECHANICAL INSTRUMENTS		ELECTRICAL INSTRUMENTS	
Cross level* Δn	Equivalent peak $(\Delta n + d\Delta n)$	Cross level* Δn	Equivalent peak $(\Delta n + d\Delta n)$
0.23	0.27	0.20	0.24
0.33	0.37	0.30	0.34
0.43	0.47	0.40	0.466
0.52	0.56	0.60	0.666
0.62	0.66	0.80	0.866
0.72	0.76	1.00	1.066
0.82	0.86	1.20	1.266
0.92	0.96	1.40	1.466
1.02	1.10	1.60	1.68

Example: (Electrical instruments)

n_j crossings of level n_z - 1.40
n_{j+1} crossings of level $n_z = 1.60$

$\rightarrow$ conversion to $(n_j - n_{j+1})$ peaks at $n_z = 1.466$

n_k crossings of level $n_z = 0.70$
n_{k+1} crossings of level $n_z = 0.60$

$\rightarrow$ conversion to $(n_k - n_{k+1})$ valleys at $n_z = 0.66$

TABLE 11. FATIGUEMETER DATA BASE—OVERVIEW OF ACCELERATION PEAK DATA

Total number of flights : 10697
Total flight hours : 25143.77
The mean flight duration: 2.35 hours

Δn_z >	Altitude < 1500	1500 4500	4500 9500	9500 14500	14500 19500	19500 24500	24500 29500	29500 34500	34500 39500	> 39500	all alt
1.02	7	4	5	1	0	0	0	0	0	0	17
1.00	7	4	5	1	0	1	0	0	0	0	18
0.92	12	15	6	6	0	1	1	4	3	0	48
0.82	29	26	19	16	1	1	1	12	10	0	115
0.80	29	28	19	22	8	5	4	13	10	0	138
0.72	68	59	49	31	13	7	4	24	19	0	274
0.62	164	148	124	74	24	13	6	32	26	0	611
0.60	166	160	139	100	59	34	18	37	30	0	743
0.52	467	500	476	251	98	57	26	65	56	2	1998
0.43	2359	2436	1767	922	242	139	39	133	116	5	8158
0.40	2396	2689	2116	1171	462	263	127	183	148	5	9560
0.33	8727	9883	7225	3732	880	479	183	425	380	21	31935
0.30	8954	11386	8764	4562	1550	837	468	602	502	23	37648
0.23	35471	41694	26146	12482	3174	1672	693	1326	1193	71	123922
0.20	37165	50902	34982	17606	7236	3849	2201	2678	2168	85	158872
-0.20	15892	30417	29025	14569	6354	3732	2003	2811	2238	69	107110
-0.23	14801	23752	22020	10509	2852	1576	546	1062	929	48	78095
-0.30	3152	5434	5980	3388	1361	772	395	572	467	17	21538
-0.33	3034	4621	5001	2686	768	402	145	386	334	15	17392
-0.40	713	1063	1360	962	461	240	101	165	132	4	5201
-0.43	659	900	1115	682	196	104	26	103	90	4	3879
-0.52	133	206	292	228	89	49	16	48	43	2	1106
-0.60	25	45	87	96	51	31	14	22	18	1	390
-0.62	25	42	69	59	22	14	5	19	17	1	273
-0.72	9	17	23	28	14	6	4	11	9	0	121
-0.80	2	4	6	13	10	5	4	6	4	0	54
-0.82	2	4	6	8	5	2	2	6	4	0	39
-0.92	1	0	1	3	3	2	1	5	3	0	19
-1.00	0	0	1	1	2	1	1	1	0	0	7
-1.02	0	0	1	0	0	1	1	1	0	0	4
-1.20	0	0	0	0	0	0	1	1	0	0	2

TABLE 12. DISTANCES FLOWN IN DIFFERENT ALTITUDE BANDS FOR THE THREE DATA BASES

Altitude band	Distance (km) ONERA data	%	Distance (km) ACMS data	%	Distance (km) Fatiguemeter data	%
< 1500	1.17e+07	0.9	3.66e+05	0.3	6.12e+04	1.7
1500 - 4500	3.89e+07	3.0	9.72e+05	0.9	1.34e+05	3.7
4500 - 9500	4.95e+07	3.8	1.62e+06	1.5	4.22e+05	11.7
9500 - 14500	4.98e+07	3.9	1.76e+06	1.7	8.37e+05	23.2
14500 - 19500	4.79e+07	3.7	1.75e+06	1.7	6.63e+05	18.4
19500 - 24500	6.04e+07	4.7	2.29e+06	2.2	4.11e+05	11.4
24500 - 29500	1.08e+08	8.4	6.34e+06	6.0	2.01e+05	5.6
29500 - 34500	4.61e+08	35.7	3.77e+07	35.9	4.65e+05	12.9
34500 - 39500	4.46e+08	34.5	5.19e+07	49.4	3.91e+05	10.9
> 39500	1.91e+07	1.5	3.53e+05	0.3	1.51e+04	0.4
all altitudes	1.29e+09	100.0	1.05e+08	100.0	3.60e+06	100.0

TABLE 13. EXCEEDANCE FREQUENCIES OF $\Delta n_z = 0.3$ AND $\Delta n_z = 0.6$ FOR VARIOUS AIRCRAFT

type	No. of flights	Exceedings $\Delta n_z = 0.3$		Exceedings $\Delta n_z = 0.6$	
		total	per flight	total	per flight
Ambassador	655	1039	1.59	33	0.0504
B-707	610	510	0.84	3	0.0049
Bristol freighter	2745	14897	5.43	283	0.1031
Brittania	345	707	2.05	13	0.0377
Comet 1	681	2252	3.31	111	0.1630
Comet 4	439	1055	2.40	21	0.0478
Hermes 4	600	1789	2.98	27	0.0450
Hermes 4a	712	1365	1.92	53	0.0744
Stratocruiser	604	4336	7.18	20	0.0331
Super Constellation	611	1531	2.51	43	0.0704
Viking	750	4699	6.27	60	0.0800
Viscount	1945	3468	1.78	76	0.0391
All Flights, Fatiguemeter Data Base	10697	37648	3.52	743	0.0695
ONERA Data Base	838657			2109	0.0025
ACMS Data Base	24358	7720	0.30	144	0.0059

TABLE 14. GEOMETRIC DATA—ONERA, ACMS, AND FATIGUEMETER DATA BASES

ONERA Data Base

a/c type	S	c	MTOW	m/S
	[m²]	[m]	[kg]	[kg/m²]
Trident 1	126.16	4.61	52163	413
Trident 2	135.73	4.54	64634	476
Trident 3	138.70	4.64	64634	466
BAC 1.11	95.78	3.36	44678	466
Tristar	320.00	6.76	224982	703
Tristar 500	329.00	6.57	224982	684
B-747	511.00	8.57	377840	739
B-737	105.40	3.65	62822	596
B-757	195.25	4.87	104325	534

ACMS Data Base

a/c type	S	c	MTOW	m/S
	[m²]	[m]	[kg]	[kg/m²]
B-747	528.20	8.57	378000	716

TABLE 14. GEOMETRIC DATA—ONERA, ACMS, AND FATIGUEMETER DATA BASES (Continued)

Fatiguemeter Data Base

A/c type	S	C	MTOW	M/S	B	Aspect	C_{L_α} *)
	[m^2]	[m]	[kg]	[kg/m^2]	[m]	ratio	[rad-1]
Ambassador	111.48	3.18	28032	251	35.00	10.99	5.837
B-707	248.60	6.92	143335	577	43.40	7.58	5.459
Bristol	138.15	4.20	20502	148	32.89	7.83	5.496
Brittania	192.70	3.21	80014	415	34.81	6.29	5.235
Comet 1	187.20	5.33	49986	267	35.00	6.54	5.285
Comet 4	196.95	5.62	73482	373	35.00	6.22	5.221
Hermes 4	130.81	4.20	44996	344	34.38	9.04	5.650
Hermes 4A	130.81	4.20	44996	344	34.38	9.04	5.650
Stratocruiser	164.35	3.81	72575	442	43.00	11.25	5.859
Constellation	153.29	4.47	62369	407	37.49	9.17	5.664
Viking	81.94	3.01	15966	195	27.20	9.03	5.649
Viscount	89.47	3.12	29257	327	28.70	9.21	5.669

*) $C_{L_\alpha} = 1.15 \cdot \frac{6A}{A+2}$

TABLE 15. ONERA DATA BASE—U_{de}-EXCEEDANCE DATA

Total number of flights : 838657
Total flight hours : 1781548
The mean flight duration: 2.12 hours

U_{de} >	Altitude < 1500	1500 4500	4500 9500	9500 14500	14500 19500	19500 24500	24500 29500	29500 34500	34500 39500	> 39500	all alt
16	2	0	0	0	0	1	0	0	0	0	3
15	2	1	0	0	0	1	0	0	0	0	4
14	2	4	3	0	0	2	1	0	0	0	12
13	4	7	5	4	2	3	1	1	1	0	28
12	6	20	12	11	4	3	4	5	2	0	67
11	9	45	33	25	6	5	4	9	5	0	141
10	15	87	80	49	16	9	7	20	15	0	298
9	27	160	195	100	38	23	15	42	33	0	633
8	32	286	367	194	78	47	36	100	65	0	1205
7	37	422	649	349	148	94	86	209	150	0	2144
6	37	571	1029	545	250	175	183	337	258	0	3385
5	37	735	1513	771	345	280	284	433	335	0	4733
4	37	791	1753	900	408	364	369	494	366	1	5483
3	37	795	1778	923	421	386	391	497	371	1	5600
2	37	795	1778	925	421	386	391	497	371	1	5602
0	37	795	1778	925	421	386	391	497	371	1	5602
0	50	551	1515	951	355	318	414	442	378	6	4980
-2	50	551	1515	951	355	318	414	442	378	6	4980
-3	50	551	1515	950	354	317	414	442	378	6	4977
-4	50	548	1490	928	345	297	394	436	375	6	4869
-5	50	519	1320	790	287	219	282	386	345	6	4204
-6	50	427	945	561	203	134	179	287	270	5	3061
-7	50	320	643	386	133	74	103	197	165	4	2075
-8	47	226	389	235	75	40	49	103	79	0	1243
-9	38	137	192	111	38	25	18	45	40	0	644
-10	23	81	95	57	19	14	12	15	22	0	338
-11	10	54	45	25	10	8	8	7	7	0	174
-12	6	29	18	13	7	7	4	2	4	0	90
-13	4	17	8	5	6	3	2	2	4	0	51
-14	3	11	3	3	4	0	1	1	2	0	28
-15	3	7	0	1	1	0	1	1	0	0	14
-16	1	6	0	0	1	0	0	0	0	0	8
-17	0	4	0	0	0	0	0	0	0	0	1
-18	0	1	0	0	0	0	0	0	0	0	1
-21	0	1	0	0	0	0	0	0	0	0	1

TABLE 16. ONERA DATA BASE—U_σ-EXCEEDANCE DATA

Total number of flights : 838657
Total flight hours : 1781548
The mean flight duration: 2.12 hours

U_σ >

	< 1500	1500 4500	4500 9500	9500 14500	14500 19500	19500 24500	24500 29500	29500 34500	34500 39500	> 39500	all alt
29.	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89
27.	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89
26.	2.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.16
24.	2.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.16
23.	2.16	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.32
22.	3.09	7.20	2.30	0.00	0.00	1.08	0.00	0.00	0.00	0.00	13.68
21.	5.24	8.96	3.21	0.00	0.00	1.08	0.83	0.00	0.00	0.00	19.32
20.	7.77	19.24	3.21	0.00	0.00	1.08	0.83	0.00	0.00	0.00	32.13
19.	10.87	30.72	9.36	1.16	0.00	1.08	0.83	0.00	0.00	0.00	54.03
18.	14.40	63.74	16.17	6.40	4.04	4.23	0.83	0.00	0.00	0.00	109.81
17.	19.87	85.83	44.82	18.54	5.46	4.23	0.83	0.00	0.00	0.00	179.58
16.	25.81	137.71	78.16	27.03	6.97	5.11	2.45	0.00	0.00	0.00	283.25
15.	27.51	208.10	133.22	53.46	9.78	6.57	4.13	3.23	1.62	0.00	447.61
14.	33.16	277.95	243.44	95.53	21.16	9.54	5.93	8.54	1.62	0.00	696.88
13.	35.81	368.61	385.42	161.25	34.83	23.91	7.02	13.65	6.51	0.00	1037.00
12.	35.81	446.98	615.84	254.94	75.63	35.35	12.29	29.79	16.36	0.00	1522.99
11.	35.81	524.54	913.00	405.48	133.70	62.71	25.05	59.19	37.06	0.00	2196.55
10.	35.81	616.95	1208.02	596.04	211.71	107.50	48.32	111.57	67.17	0.00	3003.10
9.	35.81	712.47	1534.75	817.63	343.69	178.13	125.97	214.20	128.87	0.00	4091.52
8.	35.81	756.46	1771.07	995.61	432.46	298.45	255.91	425.98	269.77	0.00	5241.52
7.	35.81	763.71	1855.01	1064.58	500.02	382.36	391.68	630.49	445.16	0.00	6068.82
6.	35.81	764.47	1866.69	1079.79	518.45	428.85	461.21	730.33	528.73	0.92	6415.27
5.	35.81	764.47	1866.69	1081.98	522.48	437.59	476.09	737.27	540.51	0.92	6463.82
4.	35.81	764.47	1866.69	1081.98	522.48	437.59	476.09	737.27	542.91	0.92	6465.22
0.	35.81	764.47	1866.69	1081.98	522.48	437.59	476.09	737.27	542.91	0.92	6466.22
0.	46.10	545.53	1640.65	1097.39	432.42	355.45	496.45	629.39	543.40	8.84	5795.62
-4.	46.10	545.53	1640.65	1097.39	432.42	355.45	496.45	629.39	543.40	8.84	5795.62
-5.	46.10	545.53	1640.65	1097.39	431.73	355.45	496.45	629.39	542.24	8.84	5793.77
-6.	46.10	545.53	1638.48	1095.21	430.99	343.34	479.80	622.26	533.01	8.84	5743.57
-7.	46.10	544.78	1628.70	1080.37	413.59	303.88	400.17	559.42	473.94	7.62	5458.58
-8.	46.10	537.52	1583.14	1007.07	362.79	220.47	267.90	378.43	288.24	6.34	4698.00
-9.	46.10	518.05	1408.55	832.21	266.29	147.33	151.22	211.06	156.44	0.00	3737.26
-10.	46.10	467.44	1134.00	647.68	191.94	90.88	77.18	105.75	75.10	0.00	2836.07
-11.	46.10	408.32	889.07	478.07	123.52	46.01	37.30	49.88	50.09	0.00	2128.37
-12.	46.10	350.41	640.12	302.27	75.48	29.40	28.72	17.54	24.74	0.00	1514.79
-13.	44.38	291.08	403.76	186.62	46.57	19.16	13.73	11.10	11.51	0.00	1027.91
-14.	41.97	236.18	255.05	107.28	29.79	16.60	7.06	2.83	6.77	0.00	703.53
-15.	41.97	177.55	149.39	59.19	19.25	13.90	3.76	2.83	5.02	0.00	472.85
-16.	37.71	126.43	75.16	39.21	13.65	10.41	3.76	2.83	3.38	0.00	312.54
-17.	29.53	93.08	46.47	17.96	9.18	6.08	0.00	2.83	0.00	0.00	205.13
-18.	23.51	63.40	26.38	7.81	5.31	0.88	0.00	0.00	0.00	0.00	127.29
-19.	15.91	44.11	15.17	5.31	3.47	0.88	0.00	0.00	0.00	0.00	84.85
-20.	10.49	30.24	6.68	5.31	3.47	0.00	0.00	0.00	0.00	0.00	56.19
-21.	8.41	19.75	5.03	1.95	0.00	0.00	0.00	0.00	0.00	0.00	35.13
-22.	5.76	15.08	0.81	1.95	0.00	0.00	0.00	0.00	0.00	0.00	23.60
-23.	4.92	13.48	0.81	0.89	0.00	0.00	0.00	0.00	0.00	0.00	20.10
-24.	4.92	9.60	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.33
-25.	1.17	8.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.76
-26.	1.17	8.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.76
-27.	1.17	6.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.40
-28.	0.00	4.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.80
-29.	0.00	3.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.36
-30.	0.00	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.27
-31.	0.00	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.27
-32.	0.00	1.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.48
-33.	0.00	1.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.48

TABLE 17. ONERA DATA BASE—ESTIMATION OF FLIGHT DURATION

Aircraft Type	(1) Block Time (hrs)	(2) Taxi, Takeoff and Roll Out (hrs)	(3) Airborne Flight Time (hrs)
B-747	5.41	0.37	5.04
B-737	1.19	0.26	0.93
B-757	1.55	0.27	1.28
Tristar	2.31	0.35	1.96
Trident	0.85	0.25	0.60
BAC 1-11	0.77	0.21	0.56

Legend:

(1) From table 1
(2) From reference 7, table II
(3) = (1) - (2)

TABLE 18. ONERA DATA BASE—ESTIMATION MISSION PROFILES

mean flight profile B-747			
altitude	time	speed	distance
[ft]	[hrs]	[m/s]	[km]
<1500	0.05	110	19.80
1500-4500	0.11	120	47.52
4500-9500	0.13	158	73.94
9500-14500	0.11	178	70.49
14500-19500	0.10	199	71.64
19500-24500	0.12	222	95.90
24500-29500	0.25	253	227.70
29500-34500	2.05	266	1963.08
34500-39500	2.05	267	1970.46
>39500	0.07	267	67.28
All altitudes	5.04		4607.82

Blocktime 5.41

mean flight profile B-737			
altitude	time	speed	distance
[ft]	[hrs]	[m/s]	[km]
<1500	0.05	79	14.22
1500-4500	0.10	124	44.64
4500-9500	0.10	157	56.52
9500-14500	0.09	174	56.38
14500-19500	0.08	193	55.58
19500-24500	0.08	217	62.50
24500-29500	0.17	223	136.48
29500-34500	0.17	226	138.31
34500-39500	0.09	227	73.55
>39500	0.00		0.00
All altitudes	0.93		638.17

Blocktime 1.19

mean flight profile B-757			
altitude	time	speed	distance
[ft]	[hrs]	[m/s]	[km]
<1500	0.05	81	14.58
1500-4500	0.10	119	42.84
4500-9500	0.10	154	55.44
9500-14500	0.09	174	56.38
14500-19500	0.08	199	57.31
19500-24500	0.09	214	69.34
24500-29500	0.18	233	150.98
29500-34500	0.18	247	160.06
34500-39500	0.37	250	333.00
>39500	0.04	255	36.72
All altitudes	1.28		976.64

Blocktime 1.55

TABLE 18. ONERA DATA BASE—ESTIMATION MISSION PROFILES (CONTINUED)

mean flight profile Tristar			
altitude	time	speed	distance
[ft]	[hrs]	[m/s]	[km]
<1500	0.05	104	18.72
1500-4500	0.10	134	48.24
4500-9500	0.11	156	61.78
9500-14500	0.10	177	63.72
14500-19500	0.08	201	57.89
19500-24500	0.09	225	72.90
24500-29500	0.13	250	117.00
29500-34500	0.62	262	584.78
34500-39500	0.62	262	584.78
>39500	0.06	265	57.24
All altitudes	1.96		1667.05

Blocktime 2.31

mean flight profile Trident			
altitude	time	speed	distance
[ft]	[hrs]	[m/s]	[km]
<1500	0.05	0	0.00
1500-4500	0.10	130	46.80
4500-9500	0.09	157	50.87
9500-14500	0.09	179	58.00
14500-19500	0.07	196	49.39
19500-24500	0.08	218	62.78
24500-29500	0.08	238	68.54
29500-34500	0.03	254	27.43
34500-39500	0.01	270	9.72
>39500	0.00		0.00
All altitudes	0.60		373.54

Blocktime 0.85

mean flight profile BAC 1-11			
altitude	time	speed	distance
[ft]	[hrs]	[m/s]	[km]
<1500	0.05	91	16.38
1500-4500	0.10	132	47.52
4500-9500	0.09	157	50.87
9500-14500	0.08	171	49.25
14500-19500	0.07	188	47.38
19500-24500	0.09	208	67.39
24500-29500	0.05	220	39.60
29500-34500	0.02	229	16.49
34500-39500	0.01	231	8.32
>39500	0.00		0.00
All altitudes	0.56		342.19

Blocktime 0.77

TABLE 19. ACMS DATA BASE—U_{de}-EXCEEDANCE DATA

Total number of flights : 24358
Total flight hours : 121893.37
The mean flight duration: 5.00 hours

U_{de} >	Altitude										
	< 1500	1500 4500	4500 9500	9500 14500	14500 19500	19500 24500	24500 29500	29500 34500	34500 39500	> 39500	all alt
distance	366048.2	972367.4	1615754.0	1760326.4	1747857.9	2294178.8	6340969.5	37730084.0	51915800.0	353490.7	105096864.0
21	1	0	0	0	0	0	0	0	0	0	1
20	1	0	0	0	0	0	0	0	0	0	1
19	1	1	0	0	0	0	0	0	0	0	2
18	3	1	0	0	0	0	0	0	0	0	4
17	3	1	0	0	0	0	0	0	0	0	4
16	5	1	0	0	0	0	0	0	0	0	6
15	12	2	0	0	0	0	0	0	0	0	14
14	17	4	0	0	1	0	0	1	0	0	23
13	22	5	1	0	1	0	0	1	0	0	30
12	41	5	1	0	1	0	0	2	0	0	50
11	73	10	5	1	2	0	0	2	0	0	93
10	130	24	13	3	3	2	0	7	1	0	183
9	244	58	25	7	3	6	0	9	4	0	356
8	509	134	49	13	7	9	5	18	11	0	755
7	1143	408	130	40	17	19	11	43	33	0	1844
6	3027	1253	399	101	39	35	32	89	79	0	5054
5	8314	4081	1302	263	101	78	81	224	229	2	14675
4	20898	12449	4322	860	264	176	242	744	759	11	40725
3	27782	30079	12744	2669	858	568	840	2845	3029	50	81464
2	28156	36857	21161	6973	2879	2012	3389	12960	14237	206	128830
1	28158	36906	21484	8126	3716	2829	4684	16661	18731	302	141597
0	28158	36906	21484	8126	3716	2829	4684	16661	18731	302	141597
0	11396	16785	11686	5800	3094	2302	3997	14831	16184	288	86363
-1	11396	16785	11686	5800	3094	2302	3997	14831	16184	288	86363
-2	11396	16749	11467	4852	2274	1609	2924	11729	12144	196	75340
-3	11193	13565	6631	1690	582	380	685	2489	2483	43	39741
-4	6369	5104	2083	539	168	93	208	614	641	7	15826
-5	1783	1392	624	196	58	38	70	221	207	2	4591
-6	585	415	218	87	24	19	28	81	86	0	1543
-7	285	180	94	31	11	11	10	37	32	0	691
-8	132	117	44	18	8	3	4	10	12	0	348
-9	68	86	25	4	4	1	2	1	6	0	197
-10	40	72	16	2	3	0	1	0	3	0	137
-11	27	52	9	0	1	0	0	0	1	0	90
-12	21	36	5	0	1	0	0	0	0	0	63
-13	15	23	3	0	1	0	0	0	0	0	42
-14	10	22	3	0	1	0	0	0	0	0	36
-15	5	16	2	0	0	0	0	0	0	0	23
-16	4	12	2	0	0	0	0	0	0	0	18
-17	3	6	1	0	0	0	0	0	0	0	10
-18	2	3	1	0	0	0	0	0	0	0	6
-19	2	3	0	0	0	0	0	0	0	0	5
-20	1	1	0	0	0	0	0	0	0	0	2

TABLE 20. ACMS DATA BASE—U_σ-EXCEEDANCE DATA

Total number of flights : 24358
Total flight hours : 121893.37
The mean flight duration: 5.00 hours

U_σ > Altitude

distance	< 1500 366048.2	1500 4500 972367.4	4500 9500 1615754.0	9500 14500 1760326.4	14500 19500 1747857.9	19500 24500 2294178.8	24500 29500 6340969.5	29500 34500 37730084.0	34500 39500 51915800.0	> 39500 353490.7	all alt 105096864.0
33	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49
29	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49
28	4.60	1.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.29
26	4.60	1.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.29
25	6.20	1.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.89
24	14.02	3.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.19
23	20.27	6.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.30
22	21.72	6.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.75
21	30.08	7.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.59
20	41.01	7.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.52
19	56.51	7.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.02
18	89.89	8.96	3.15	0.00	1.75	0.00	0.00	1.53	0.00	0.00	105.28
17	130.72	17.84	4.62	0.00	1.75	0.00	0.00	1.53	0.00	0.00	156.46
16	186.10	28.09	10.51	1.74	1.75	0.00	0.00	1.53	0.00	0.00	229.72
15	260.06	51.54	21.47	4.94	1.75	0.00	0.00	3.04	0.00	0.00	342.80
14	386.43	82.40	31.00	6.47	5.18	0.00	0.00	3.04	0.00	0.00	514.52
13	651.23	139.49	48.16	11.35	5.18	1.76	0.00	4.57	0.00	0.00	861.74
12	1068.89	289.94	79.56	17.44	5.18	6.82	0.00	7.78	1.58	0.00	1477.19
11	1806.79	553.90	144.31	34.88	11.79	13.46	4.84	14.26	6.18	0.00	2590.41
10	3336.30	1182.65	283.24	62.97	27.86	26.01	8.02	17.55	10.76	0.00	4955.36
9	6109.44	2417.78	628.50	129.06	40.88	30.96	12.57	39.51	32.19	0.00	9440.89
8	11430.99	5198.93	1403.47	255.55	82.66	58.32	38.71	87.86	65.27	0.00	18621.76
7	21337.75	10735.54	3125.66	506.41	149.56	99.16	71.29	165.44	131.54	0.00	36322.35
6	35986.83	22068.12	6936.31	1127.70	284.18	173.07	154.31	351.88	330.45	1.44	67414.29
5	41911.08	40248.65	14656.49	2508.33	679.49	360.72	380.51	948.74	873.82	7.28	102575.11
4	42736.20	53640.26	26406.21	5510.52	1558.04	882.45	1011.48	2785.23	2660.38	39.20	137229.97
3	42782.01	55675.51	32690.15	10568.58	3966.62	2379.84	3243.04	9989.03	9769.74	147.54	171212.06
2	42783.52	55719.73	33108.55	12684.82	5857.62	4462.75	7425.23	26378.55	28549.73	433.74	217404.25
1	42783.52	55719.73	33110.05	12684.82	5860.57	4474.62	7512.06	26659.40	28767.90	436.54	218009.22
0	42783.52	55719.73	33110.05	12684.82	5860.57	4474.62	7512.06	26659.40	28767.90	436.54	218009.22
0	17236.75	25490.35	18281.66	9125.81	4871.33	3651.77	6448.37	23831.95	24844.31	415.26	134197.58
-1	17236.75	25490.35	18281.66	9125.81	4871.33	3651.77	6448.37	23831.95	24844.31	415.26	134197.58
-2	17236.75	25490.35	18281.66	9125.81	4866.91	3637.08	6367.43	23625.40	24647.45	406.90	133685.75
-3	17236.75	25467.11	18000.84	7412.90	2989.08	1778.23	2713.76	8708.43	7859.56	103.87	92270.53
-4	17225.31	24414.84	13919.79	3580.82	1031.49	578.62	859.78	2425.61	2192.34	24.43	66253.03
-5	16656.04	17970.83	7232.85	1522.51	441.61	191.16	339.02	795.80	736.75	4.41	45890.98
-6	11855.07	9224.48	3218.39	705.31	184.76	83.92	131.37	331.71	306.34	2.91	26044.26
-7	5493.85	3830.79	1443.15	352.36	82.55	43.33	62.31	147.18	147.89	0.00	11603.41
-8	2408.18	1671.22	667.57	191.54	35.75	29.30	32.81	71.05	64.86	0.00	5172.28
-9	1173.29	781.46	331.63	96.34	25.76	24.75	13.24	35.52	24.70	0.00	2506.69
-10	667.13	398.92	174.67	44.22	14.63	9.16	4.73	8.11	12.55	0.00	1334.12
-11	425.64	249.00	102.28	30.02	11.36	4.61	3.13	1.60	9.40	0.00	837.04
-12	263.09	189.29	66.88	23.59	9.74	1.56	3.13	0.00	3.09	0.00	560.37
-13	170.64	153.91	46.40	6.31	4.97	0.00	1.50	0.00	1.61	0.00	385.34
-14	107.58	133.12	28.74	3.05	4.97	0.00	0.00	0.00	0.00	0.00	277.46
-15	68.40	115.36	23.64	3.05	1.74	0.00	0.00	0.00	0.00	0.00	212.19
-16	50.88	102.06	15.89	0.00	1.74	0.00	0.00	0.00	0.00	0.00	170.57
-17	39.59	85.67	9.29	0.00	1.74	0.00	0.00	0.00	0.00	0.00	136.29
-18	34.66	65.58	7.61	0.00	1.74	0.00	0.00	0.00	0.00	0.00	109.59
-19	24.97	47.37	6.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	78.55
-20	23.24	37.29	6.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.74
-21	18.46	34.40	4.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	57.68
-22	15.38	32.95	4.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	53.15
-23	9.34	30.07	3.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42.78
-24	7.98	21.42	3.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.77
-25	6.47	18.37	1.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.52
-26	4.80	10.82	1.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.30
-27	3.16	6.36	1.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.20
-28	3.16	4.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.05
-29	3.16	4.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.05
-30	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49
-32	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49

TABLE 21. FATIGUEMETER DATA BASE—U_{de}-EXCEEDANCE DATA

Total number of flights : 10697
Total flight hours : 25143.77
The mean flight duration: 2.35 hours

U_{de} >	Altitude										
	< 1500	1500 4500	4500 9500	9500 14500	14500 19500	19500 24500	24500 29500	29500 34500	34500 39500	> 39500	all alt
distance	61168.6	134413.5	422241.6	837051.3	662558.4	411309.2	201060.3	464611.2	391116.5	15130.1	3600660.8
20	1	0	0	0	0	0	0	0	0	0	1
18	1	0	0	0	0	0	0	0	0	0	1
17	2	0	0	0	0	0	0	0	0	0	2
16	2	1	1	0	0	0	0	0	0	0	4
15	3	1	2	0	0	1	0	0	0	0	7
14	3	5	2	0	0	2	1	0	0	0	13
13	4	5	5	0	0	2	1	0	0	0	17
12	9	15	7	1	3	4	1	0	0	0	40
11	17	25	14	4	5	4	3	0	0	0	72
10	29	38	77	10	7	5	3	0	0	0	169
9	62	77	100	22	13	11	5	0	0	0	290
8	167	204	172	55	39	22	6	2	1	0	668
7	349	486	582	157	73	48	28	8	4	0	1735
6	973	1480	1220	385	218	126	44	21	13	0	4480
5	2369	3503	3476	1066	469	306	114	50	32	0	11385
4	6013	10785	7436	2810	1183	731	259	137	96	3	29453
3	14232	25892	18623	9152	3612	1958	667	428	326	15	74905
2	35678	48689	33416	16712	6916	3749	2098	2045	1610	60	150973
1	37165	50765	34896	17463	7227	3849	2201	2678	2168	85	158497
0	37165	50902	34982	17606	7236	3849	2201	2678	2168	85	158872
0	15892	30417	29025	14569	6354	3732	2003	2811	2238	69	107110
-1	15892	30350	28970	14503	6340	3732	2003	2811	2238	69	106908
-2	15318	29315	27833	13878	6082	3591	1905	2133	1661	49	101765
-3	7002	16733	14702	7629	3293	1996	593	436	334	14	52732
-4	3071	6504	4996	2269	1121	739	238	133	93	3	19167
-5	1173	1825	2056	817	456	281	97	42	26	0	6773
-6	378	721	641	334	213	136	34	13	8	0	2478
-7	125	207	290	152	79	54	23	5	3	0	938
-8	39	79	77	52	44	20	4	3	1	0	319
-9	13	27	39	21	14	8	4	2	0	0	128
-10	4	11	33	6	6	5	4	1	0	0	70
-11	1	5	4	2	4	5	4	1	0	0	26
-12	0	4	1	0	3	3	2	1	0	0	14
-13	0	0	0	0	1	1	2	0	0	0	4
-14	0	0	0	0	0	1	2	0	0	0	3
-15	0	0	0	0	0	0	1	0	0	0	1
-21	0	0	0	0	0	0	1	0	0	0	1

TABLE 22. FATIGUREMETER DATA BASE—U_σ-EXCEEDANCE DATA

Total number of flights : 10697
Total flightshours : 25143.77
The mean flight duration: 2.35 hours

U_σ >	Altitude										
	< 1500	1500 4500	4500 9500	9500 14500	14500 19500	19500 24500	24500 29500	29500 34500	34500 39500	> 39500	all alt
distance	61168.6	134413.5	422241.6	837051.3	662558.4	411309.2	201060.3	464611.2	391116.5	15130.1	3600660.8
40	0.57	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70
36	0.57	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70
35	1.14	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50
33	1.14	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50
32	1.71	0.71	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80
31	1.71	0.71	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80
30	2.26	0.90	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.50
28	2.26	0.90	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.50
27	3.13	2.29	1.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.80
26	4.10	4.21	1.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.70
25	4.67	4.67	2.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.50
24	5.81	7.54	3.60	0.19	0.00	0.00	0.00	0.00	0.00	0.00	17.10
23	8.02	10.74	6.61	0.19	0.00	0.00	0.00	0.00	0.00	0.00	25.50
22	12.40	12.34	7.01	0.19	0.37	0.61	0.00	0.00	0.00	0.00	32.90
21	14.93	15.48	8.78	0.97	0.37	0.61	0.00	0.00	0.00	0.00	41.10
20	17.85	20.90	12.81	1.17	0.37	1.22	1.21	0.12	0.00	0.00	55.60
19	27.85	32.50	17.64	3.89	0.37	1.22	1.21	0.12	0.00	0.00	84.70
18	33.59	40.29	19.35	6.19	2.35	1.65	1.21	0.12	0.00	0.00	104.70
17	52.92	54.19	28.93	12.47	4.25	3.49	1.21	0.12	0.00	0.00	157.50
16	117.04	107.71	92.22	15.10	6.13	4.08	2.38	0.24	0.00	0.00	344.90
15	167.11	177.20	126.44	22.27	10.51	5.68	3.23	0.32	0.00	0.00	512.70
14	230.33	248.66	181.27	41.47	12.44	7.89	3.82	0.38	0.00	0.00	726.20
13	443.96	465.93	289.45	61.53	31.28	12.70	4.48	0.91	0.36	0.00	1310.60
12	695.60	868.24	493.93	110.35	50.30	27.25	9.28	1.87	0.73	0.00	2257.50
11	988.37	1320.90	930.12	225.22	90.23	40.46	13.96	3.29	1.47	0.00	3664.00
10	1557.73	2105.36	1480.07	474.54	142.97	85.67	22.65	10.51	6.41	0.00	5885.90
9	3050.69	4631.71	2404.58	755.02	278.46	144.38	38.22	17.87	10.92	0.00	11331.80
8	4758.27	7257.10	4434.37	1438.54	443.49	257.59	100.26	33.75	19.07	0.20	18742.60
7	7596.90	12442.91	7674.42	2429.96	772.38	425.84	151.90	54.09	31.49	0.41	31580.30
6	10303.43	18574.82	12937.87	4899.22	1442.18	726.71	266.34	111.45	71.56	1.86	49335.40
5	19234.73	28375.94	19474.80	8961.10	3223.17	1580.69	545.38	241.68	159.94	4.80	81802.20
4	22662.56	33457.23	24312.46	12312.13	5066.23	2412.82	1145.39	559.37	386.86	13.63	102328.60
3	22691.36	33681.94	24958.48	13146.26	5993.44	3139.48	1693.11	1800.39	1424.49	51.96	108580.80
2	22697.27	33764.05	25111.50	13237.57	6027.05	3193.04	1795.22	2579.29	2096.02	76.51	110577.50
1	22697.27	33768.08	25141.07	13284.23	6027.35	3193.04	1795.22	2579.29	2096.02	76.51	110658.00
0	22697.27	33768.08	25141.07	13284.23	6027.35	3193.04	1795.22	2579.29	2096.02	76.51	110658.00
0	9935.29	20451.60	20293.30	10956.06	5233.13	3137.64	1664.02	2821.49	2263.38	66.10	76822.00
-1	9935.29	20451.60	20293.30	10954.23	5233.13	3137.64	1664.02	2821.49	2263.38	66.10	76820.20
-2	9935.29	20449.37	20274.28	10935.22	5229.53	3137.64	1664.02	2821.49	2263.38	66.10	76776.30
-3	9931.70	20406.11	20138.09	10859.64	5197.95	3063.59	1526.52	1892.58	1485.20	43.98	74545.30
-4	9912.79	20252.07	19473.79	10111.00	4391.20	2334.02	962.94	539.07	380.21	11.94	68369.00
-5	8549.58	17712.36	15921.12	7510.69	2907.86	1633.33	481.77	230.00	154.11	4.23	55105.00
-6	5420.50	12162.39	10400.76	3942.69	1346.00	749.77	247.42	110.73	71.21	1.44	34452.90
-7	3725.39	7821.31	5535.84	1897.50	716.32	394.73	131.46	46.96	27.54	0.41	20297.40
-8	2428.23	4224.26	2956.00	1127.70	427.45	248.23	86.23	19.18	9.45	0.41	11527.10
-9	1487.83	2709.41	1480.83	620.91	278.29	142.03	34.94	9.91	4.99	0.00	6769.10
-10	569.57	1012.14	896.20	394.36	139.42	85.62	15.27	5.02	2.72	0.00	3120.30
-11	350.49	626.21	524.24	203.51	89.20	43.66	11.17	3.72	2.03	0.00	1854.20
-12	248.07	419.90	235.01	113.58	54.44	27.40	7.04	2.36	1.29	0.00	1109.10
-13	155.29	191.30	138.99	64.60	36.72	14.96	5.36	1.72	0.92	0.00	609.80
-14	74.99	100.15	73.01	34.89	15.21	10.07	4.24	1.14	0.56	0.00	314.20
-15	55.52	72.67	51.09	18.43	10.38	5.12	2.43	0.96	0.56	0.00	217.10
-16	23.86	33.02	38.75	13.06	6.60	2.89	2.43	0.96	0.56	0.00	122.10
-17	11.69	16.66	9.20	9.47	3.40	2.59	1.84	0.18	0.00	0.00	55.00
-18	4.57	8.82	5.08	2.25	2.24	1.98	1.84	0.18	0.00	0.00	26.90
-19	4.14	7.09	2.41	2.25	2.24	1.98	1.84	0.18	0.00	0.00	22.10
-20	1.48	4.47	1.27	0.43	1.89	1.06	1.17	0.12	0.00	0.00	11.80
-21	0.46	1.18	0.67	0.12	1.11	0.77	0.59	0.06	0.00	0.00	4.90
-22	0.00	0.80	0.00	0.12	0.82	0.29	0.59	0.06	0.00	0.00	2.60
-23	0.00	0.00	0.00	0.00	0.00	0.29	0.59	0.06	0.00	0.00	0.90
-30	0.00	0.00	0.00	0.00	0.00	0.29	0.59	0.06	0.00	0.00	0.90

TABLE 23. U_{DE}-EXCEEDANCES FOR THE COMBINED DATA BASE

U_{de}	Altitude [ft]				
[m/s]	< 1500	1500-4500	4500-9500	9500-14500	14500-19500
16	0.00	0.00	0.00	0.00	0.00
15	2.03e-05	2.04e-07	0.00	0.00	0.00
14	3.31e-05	5.12e-07	6.06e-08	0.00	0.00
13	4.62e-05	8.42e-07	1.28e-07	8.99e-08	1.08e-07
12	7.58e-05	1.86e-06	2.97e-07	2.40e-07	1.66e-07
11	1.18e-04	5.00e-06	7.78e-07	5.34e-07	2.43e-07
10	1.96e-04	1.61e-05	2.20e-06	1.40e-06	5.46e-07
9	3.69e-04	4.23e-05	7.94e-06	3.01e-06	1.43e-06
8	7.96e-04	9.82e-05	2.87e-05	8.69e-06	3.47e-06
7	1.83e-03	2.79e-04	6.84e-05	2.00e-05	7.82e-06
6	4.59e-03	7.42e-04	1.83e-04	5.33e-05	1.75e-05
5	1.32e-02	2.45e-03	5.58e-04	1.29e-04	4.38e-05
4	3.73e-02	8.20e-03	1.86e-03	3.87e-04	1.20e-04
3	6.47e-02	2.08e-02	5.69e-03	1.21e-03	4.04e-04
2	9.67e-02	2.56e-02	9.64e-03	3.30e-03	1.46e-03
1	9.88e-02	2.56e-02	9.81e-03	3.90e-03	1.94e-03
0	9.88e-02	2.56e-02	9.81e-03	3.90e-03	1.94e-03

U_{de}	Altitude [ft]				
[m/s]	19500-24500	24500-29500	29500-34500	34500-39500	> 39500
16	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
14	0.00	9.24e-09	0.00	0.00	0.00
13	9.94e-08	1.31e-08	3.07e-09	4.49e-09	0.00
12	1.52e-07	2.61e-08	6.87e-09	6.34e-09	0.00
11	2.10e-07	5.23e-08	1.72e-08	1.33e-08	0.00
10	3.72e-07	8.47e-08	3.76e-08	4.41e-08	0.00
9	7.95e-07	2.09e-07	9.44e-08	9.44e-08	0.00
8	1.90e-06	4.58e-07	2.41e-07	2.21e-07	0.00
7	5.16e-06	1.26e-06	8.29e-07	6.26e-07	0.00
6	1.12e-05	4.72e-06	2.25e-06	1.59e-06	0.00
5	2.37e-05	1.19e-05	5.90e-06	4.19e-06	1.13e-05
4	5.58e-05	3.54e-05	1.79e-05	1.34e-05	4.96e-05
3	2.03e-04	1.20e-04	7.05e-05	5.28e-05	2.62e-04
2	7.84e-04	4.96e-04	3.27e-04	2.53e-04	1.14e-03
1	1.11e-03	6.82e-04	4.17e-04	3.35e-04	1.67e-03
0	1.11e-03	6.82e-04	4.17e-04	3.35e-04	1.67e-03

TABLE 24. DERIVED P_1, P_2 AND b_1, b_2 VALUES

Altitude band [ft]	Altitude [ft]	P_1	P_2	b_1 [m/s TAS]	b_2 [m/s TAS]	b_1 [m/s EAS]	b_2 [m/s EAS]
< 1500	750	3.797e-01	-	1.58	-	1.56	-
1500- 4500	3000	1.888e-01	1.628e-03	1.36	2.37	1.30	2.27
4500- 9500	7000	5.094e-02	8.261e-04	1.38	2.08	1.24	1.87
9500- 14500	12000	8.877e-03	2.959e-04	1.48	2.39	1.23	1.99
14500- 19500	17000	4.783e-03	5.819e-05	1.44	2.98	1.11	2.29
19500- 24500	22000	2.757e-03	3.446e-05	1.47	3.17	1.04	2.24
24500- 29500	27000	1.869e-03	1.682e-05	1.49	2.94	0.96	1.90
29500- 34500	32000	1.220e-03	2.033e-05	1.52	2.65	0.90	1.56
34500- 39500	37000	1.337e-03	2.229e-05	1.55	2.84	0.83	1.51
> 39500	40000	4.764e-03	-	1.40	-	0.70	-

TABLE 25. $N(|U_\sigma|)$ AS A FUNCTION OF U_σ AND ALTITUDE

$[N_0(0)_{ref} = 8\ km^{-1}]$

$\|U_\sigma\|$ >	Altitude band [ft]								
[eas]	< 1500	1500- 4500	4500- 9500	9500- 14500	14500- 19500	19500- 24500	24500- 29500	29500- 34500	34500- 39500
25	3.290E-07	2.125E-07	1.003E-08	7.089E-09	6.628E-09	2.845E-09	1.738E-10	1.097E-11	6.453E-12
24	6.247E-07	3.341E-07	1.746E-08	1.177E-08	1.026E-08	4.446E-09	2.942E-10	2.084E-11	1.251E-11
23	1.186E-06	5.274E-07	3.058E-08	1.958E-08	1.589E-08	6.949E-09	4.982E-10	3.957E-11	2.427E-11
22	2.251E-06	8.375E-07	5.394E-08	3.263E-08	2.462E-08	1.086E-08	8.438E-10	7.518E-11	4.707E-11
21	4.274E-06	1.340E-06	9.597E-08	5.455E-08	3.817E-08	1.699E-08	1.430E-09	1.429E-10	9.129E-11
20	8.114E-06	2.167E-06	1.725E-07	9.156E-08	5.924E-08	2.658E-08	2.423E-09	2.718E-10	1.771E-10
19	1.540E-05	3.549E-06	3.140E-07	1.545E-07	9.208E-08	4.161E-08	4.112E-09	5.175E-10	3.438E-10
18	2.924E-05	5.907E-06	5.797E-07	2.624E-07	1.435E-07	6.522E-08	6.990E-09	9.870E-10	6.675E-10
17	5.551E-05	1.003E-05	1.087E-06	4.496E-07	2.246E-07	1.024E-07	1.191E-08	1.888E-09	1.298E-09
16	1.054E-04	1.741E-05	2.076E-06	7.790E-07	3.537E-07	1.614E-07	2.040E-08	3.627E-09	2.527E-09
15	2.001E-04	3.101E-05	4.034E-06	1.369E-06	5.624E-07	2.557E-07	3.519E-08	7.015E-09	4.936E-09
14	3.798E-04	5.672E-05	7.986E-06	2.445E-06	9.075E-07	4.088E-07	6.143E-08	1.371E-08	9.690E-09
13	7.211E-04	1.066E-04	1.610E-05	4.452E-06	1.496E-06	6.629E-07	1.093E-07	2.723E-08	1.919E-08
12	1.369E-03	2.053E-04	3.299E-05	8.287E-06	2.539E-06	1.099E-06	2.000E-07	5.535E-08	3.853E-08
11	2.599E-03	4.049E-04	6.868E-05	1.579E-05	4.484E-06	1.881E-06	3.811E-07	1.161E-07	7.912E-08
10	4.934E-03	8.144E-04	1.449E-04	3.081E-05	8.301E-06	3.369E-06	7.656E-07	2.541E-07	1.681E-07
9	9.366E-03	1.665E-03	3.094E-04	6.157E-05	1.620E-05	6.389E-06	1.637E-06	5.846E-07	3.751E-07
8	1.778E-02	3.450E-03	6.671E-04	1.257E-04	3.333E-05	1.292E-05	3.740E-06	1.420E-06	8.911E-07
7	3.376E-02	7.223E-03	1.450E-03	2.619E-04	7.191E-05	2.788E-05	9.075E-06	3.639E-06	2.274E-06
6	6.408E-02	1.524E-02	3.172E-03	5.548E-04	1.613E-04	6.368E-05	2.314E-05	9.772E-06	6.231E-06
5	1.217E-01	3.236E-02	6.976E-03	1.192E-03	3.729E-04	1.521E-04	6.120E-05	2.725E-05	1.816E-05
4	2.310E-01	6.899E-02	1.540E-02	2.590E-03	8.804E-04	3.753E-04	1.660E-04	7.816E-05	5.549E-05
3	4.385E-01	1.476E-01	3.413E-02	5.678E-03	2.109E-03	9.464E-04	4.580E-04	2.287E-04	1.753E-04
2	8.324E-01	3.165E-01	7.580E-02	1.253E-02	5.102E-03	2.420E-03	1.277E-03	6.780E-04	5.655E-04
1	1.580E+00	6.799E-01	1.687E-01	2.782E-02	1.242E-02	6.244E-03	3.583E-03	2.028E-03	1.850E-03
0	3.000E+00	1.463E+00	3.760E-01	6.200E-02	3.036E-02	1.620E-02	1.009E-02	6.100E-03	6.098E-03

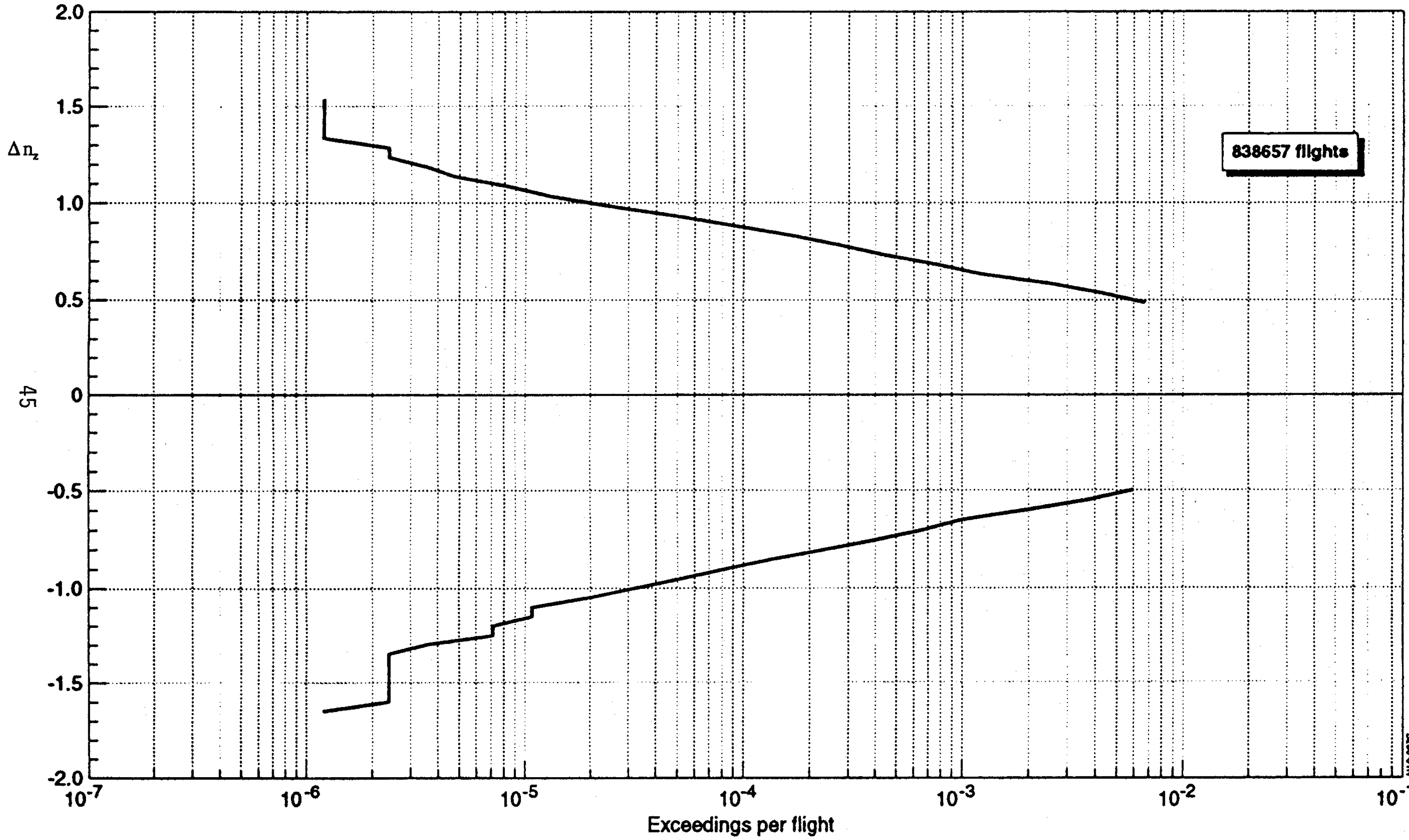

FIGURE 1. ONERA DATA BASE: LOAD FACTOR SPECTRUM PER FLIGHT

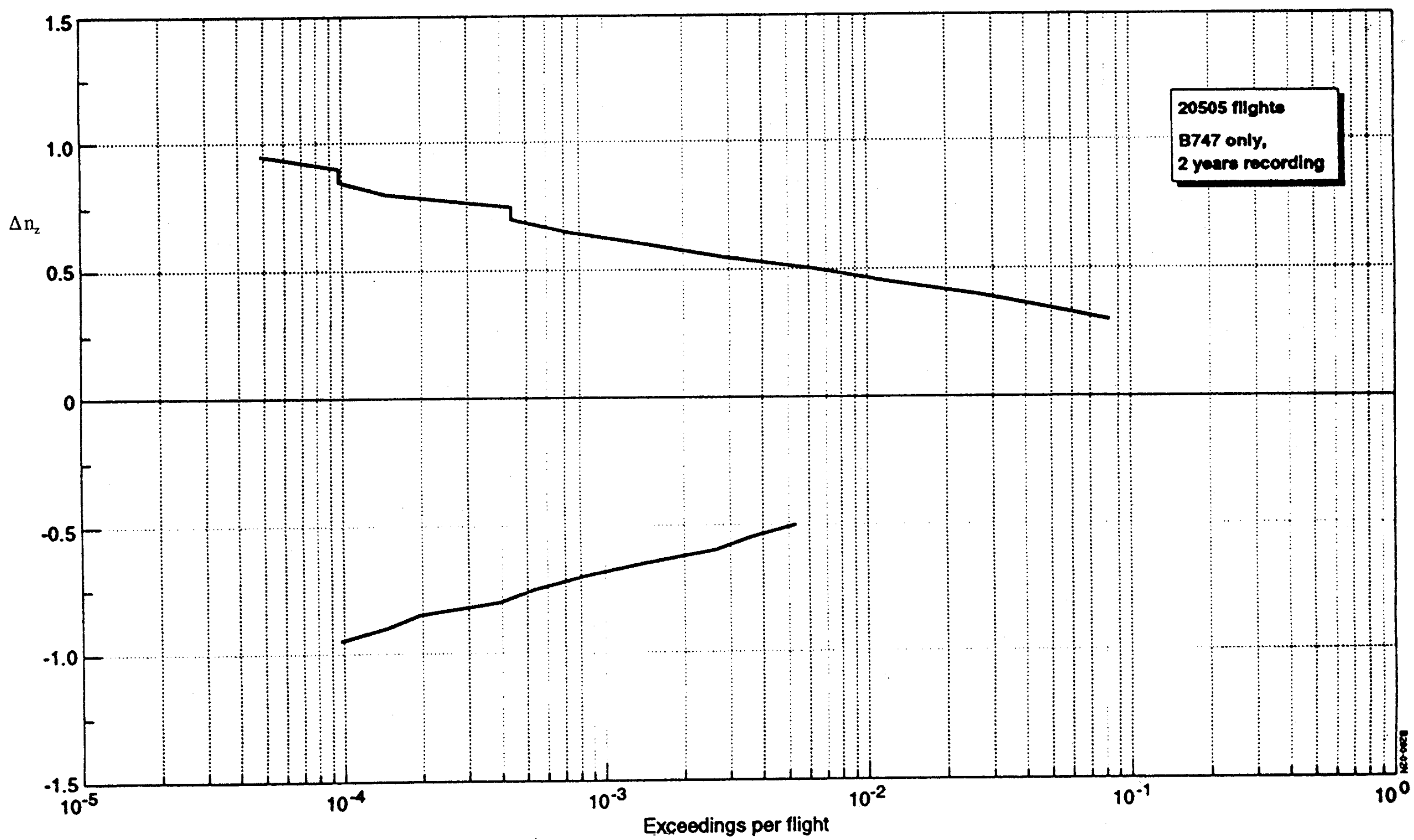

FIGURE 2. ONERA DATA BASE: Δn_z SPECTRUM FOR B-747, INCLUDING $\Delta n_z>0.3$

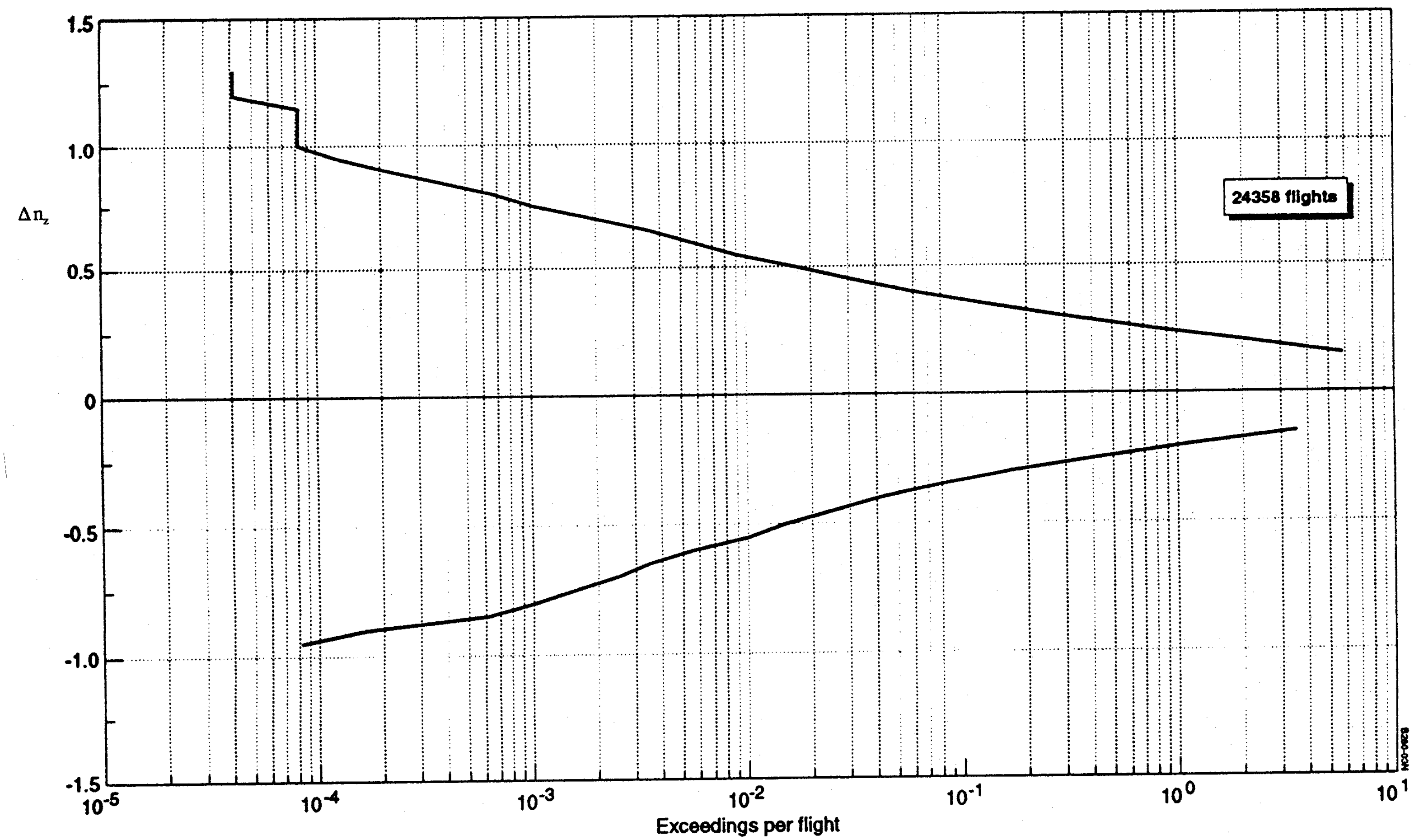

FIGURE 3. ACMS DATA BASE: LOAD FACTOR SPECTRUM PER FLIGHT

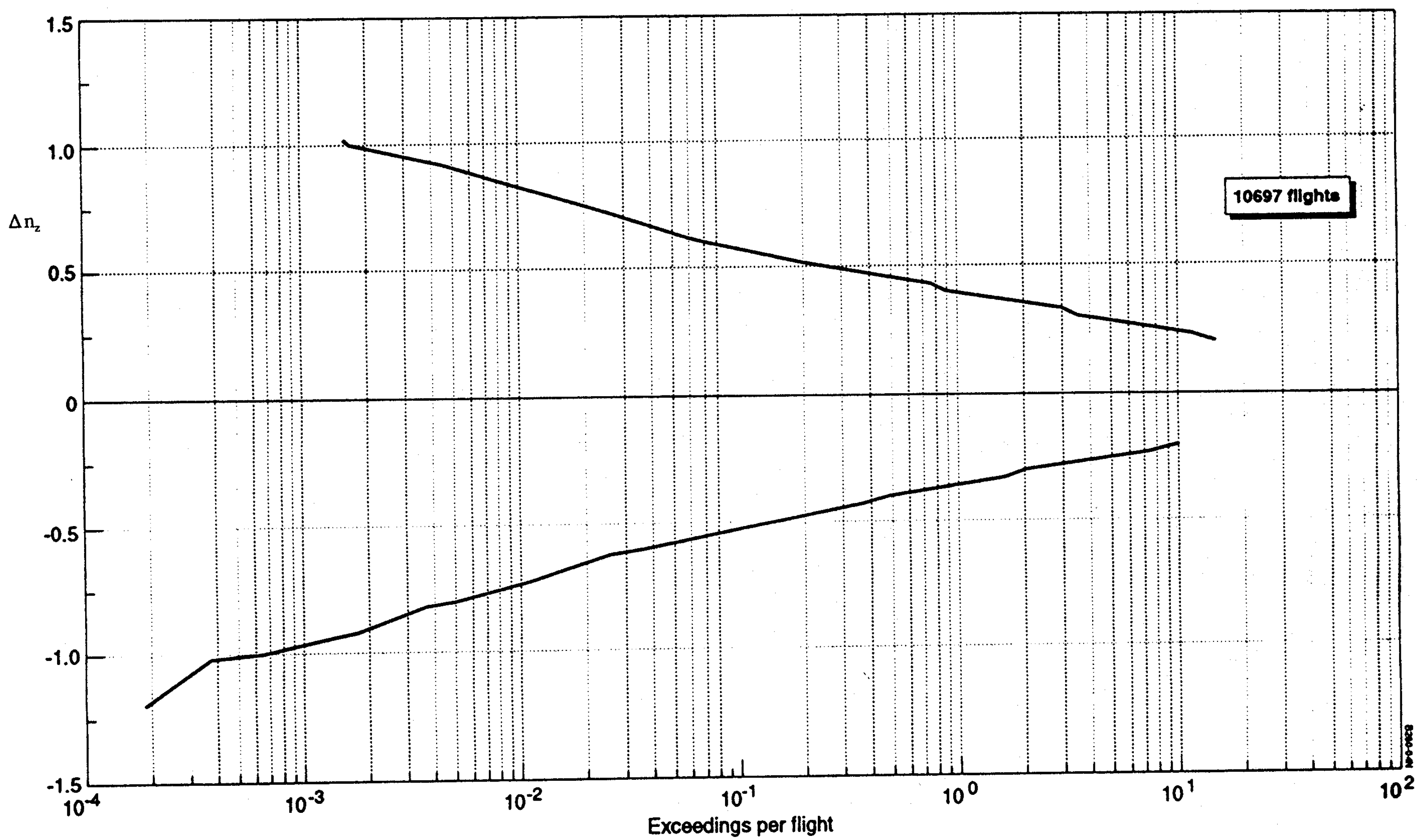

FIGURE 4. FATIGUEMETER DATA BASE: LOAD FACTOR SPECTRUM PER FLIGHT

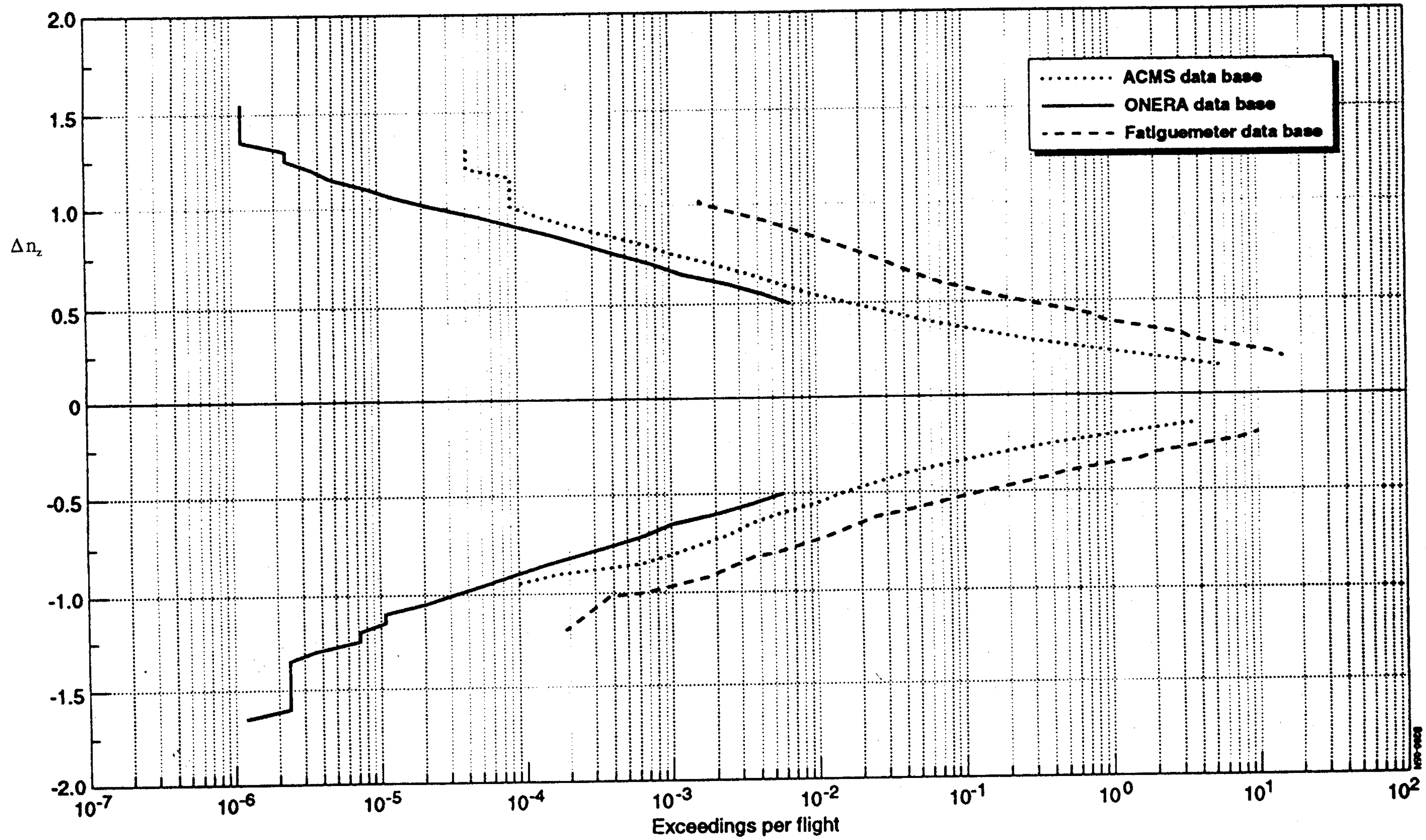

FIGURE 5. COMPARISON OF LOAD FACTOR SPECTRA FOR THREE DATA BASES

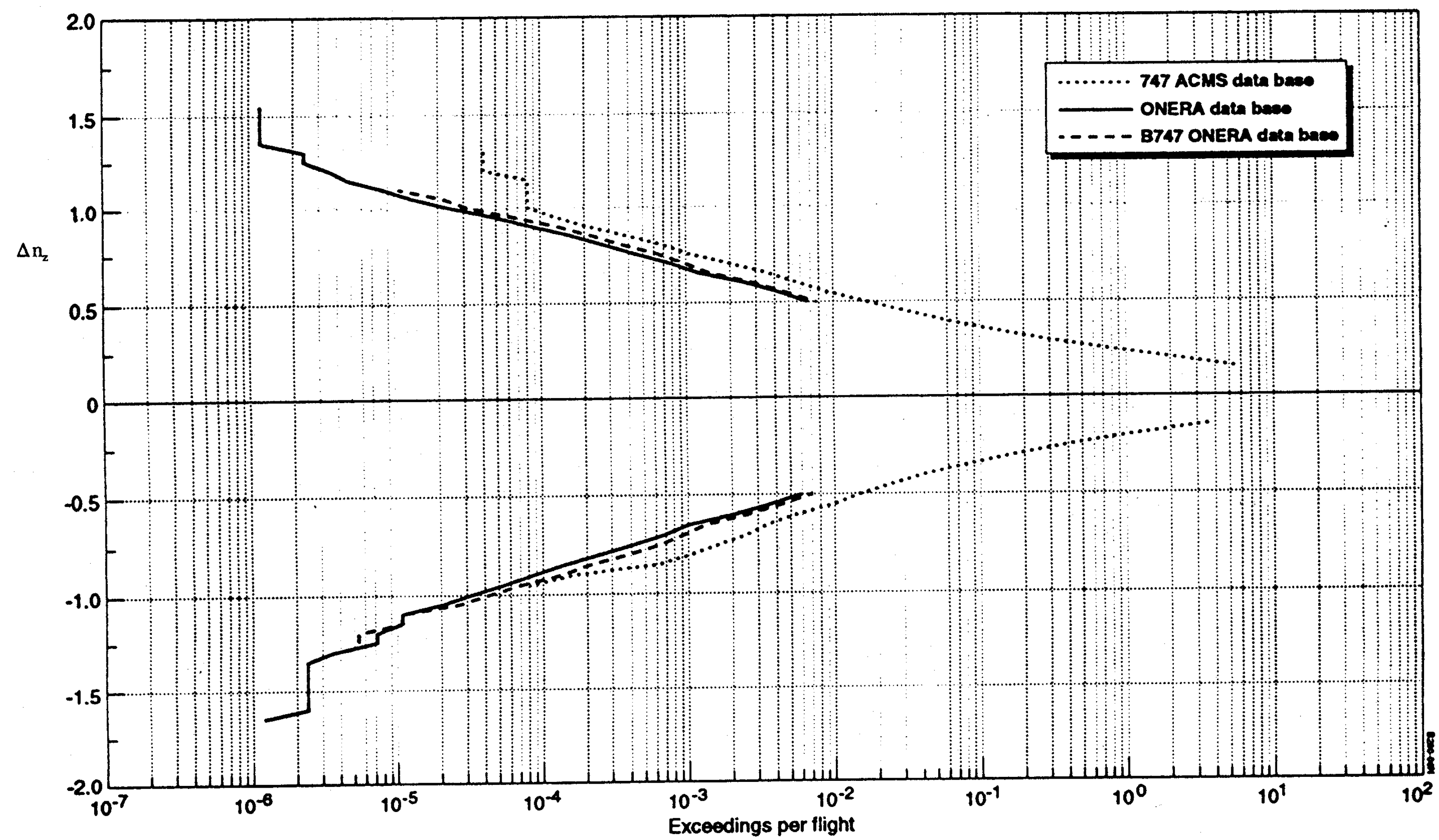

FIGURE 6. COMPARISON OF LOAD FACTOR SPECTRA FOR B-747

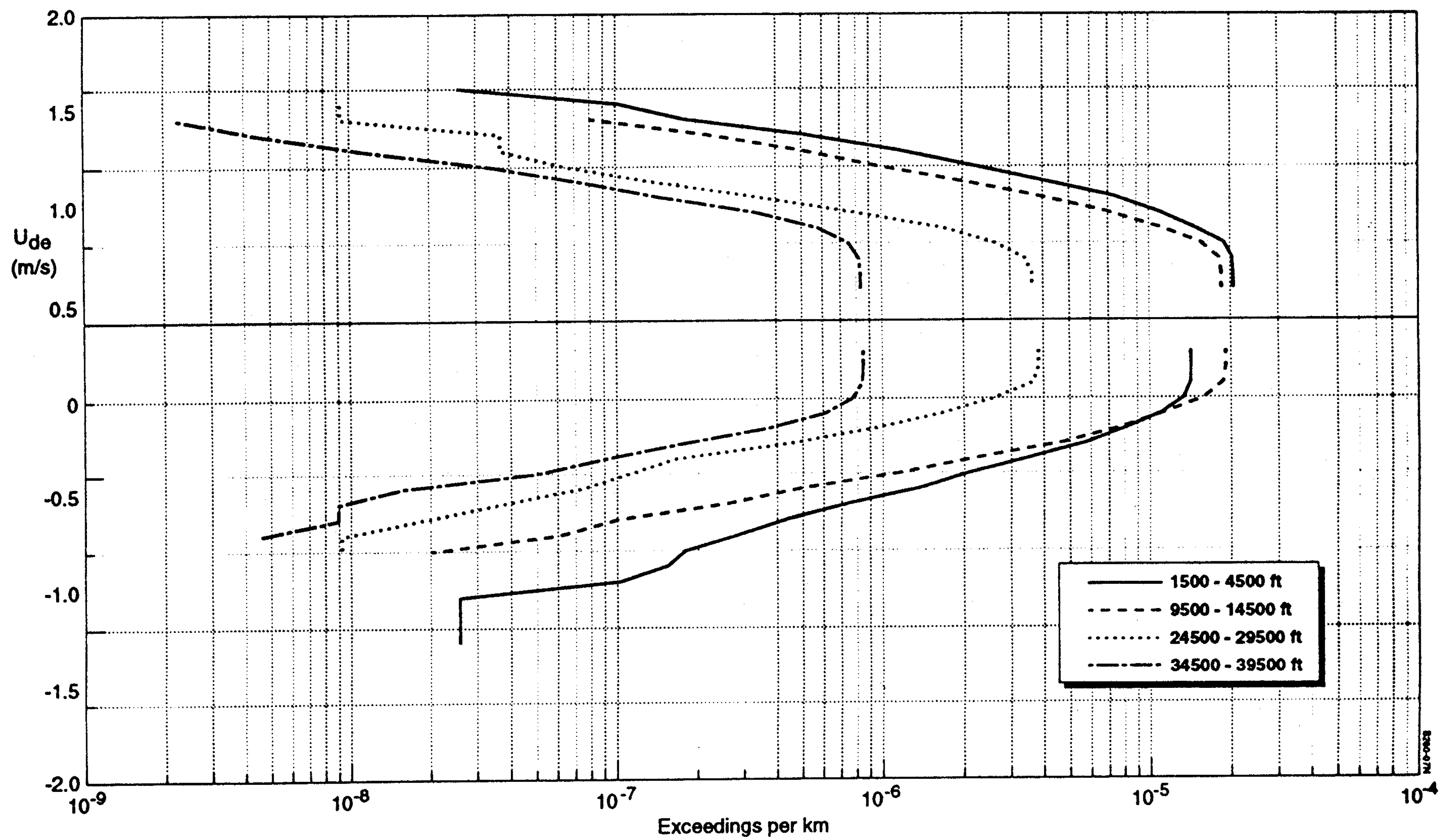

FIGURE 7. ONERA DATA BASE: U_{de}-EXCEEDANCES PER KM FOR FOUR ALTITUDE BANDS

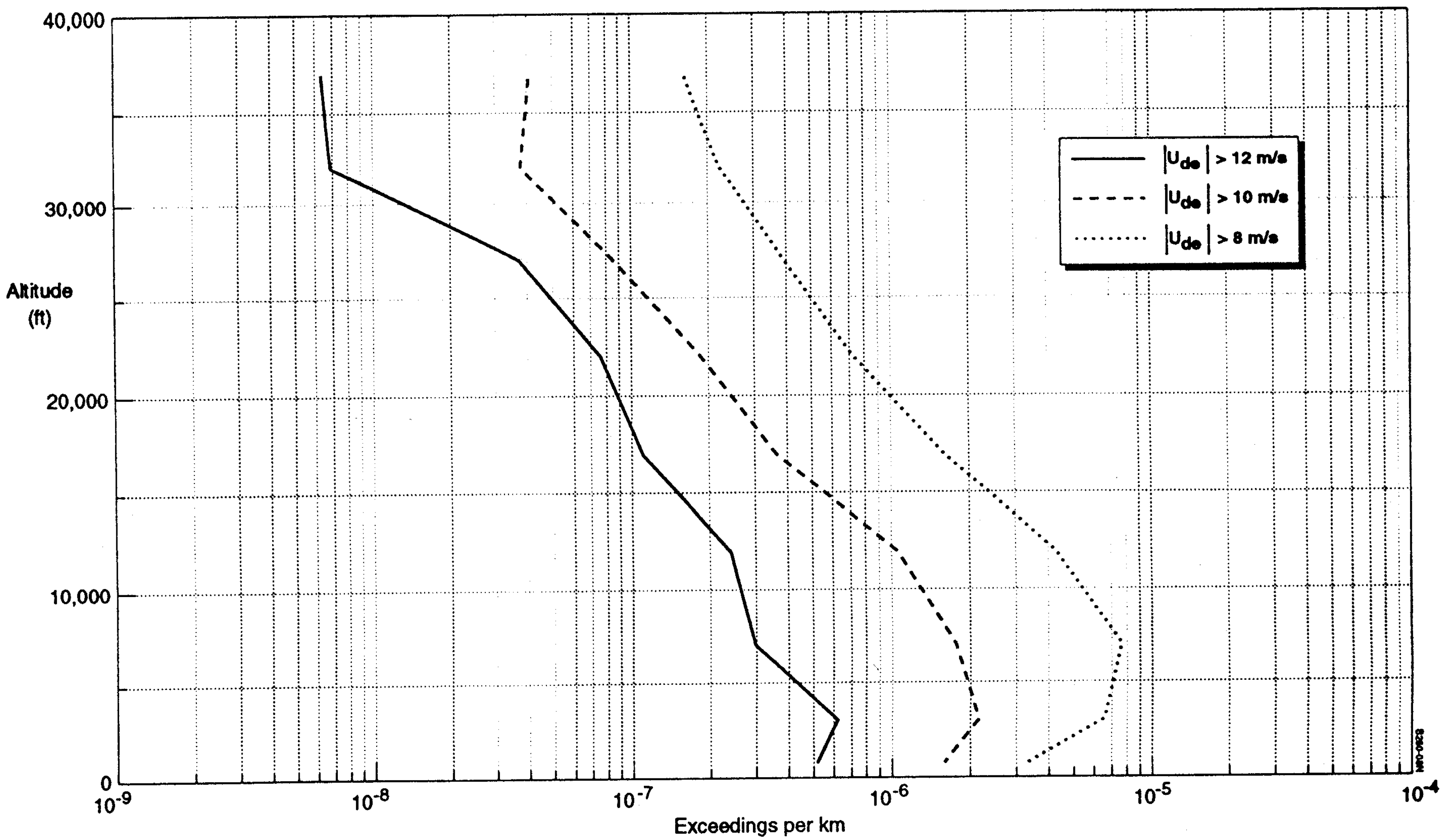

FIGURE 8. ONERA DATA BASE: EXCEEDANCES FREQUENCIES OF THREE U_{de} AS FUNCTION OF ALTITUDE

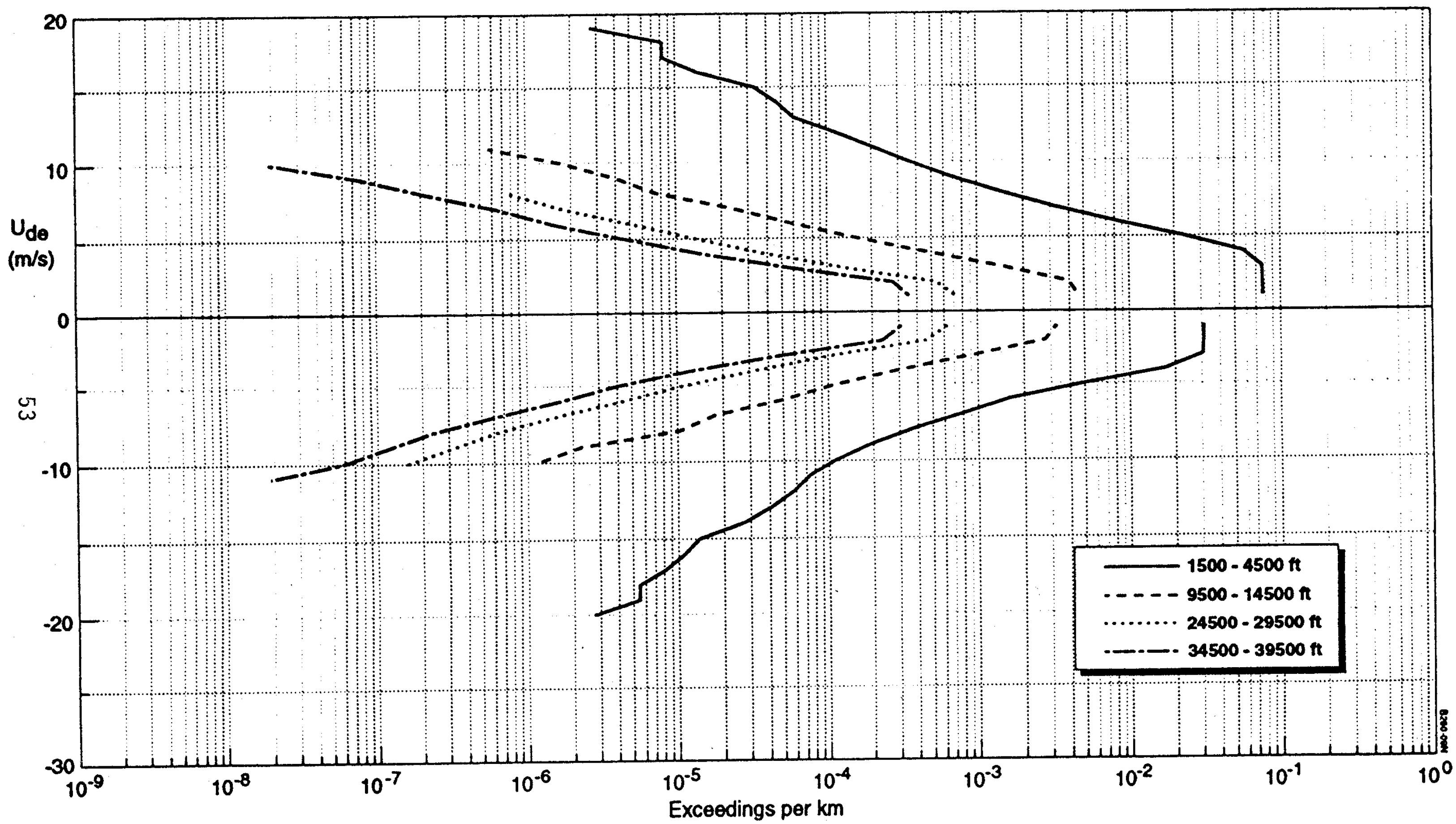

FIGURE 9. ACMS DATA BASE: U_{de}-EXCEEDANCES PER KM FOR FOUR ALTITUDE BANDS

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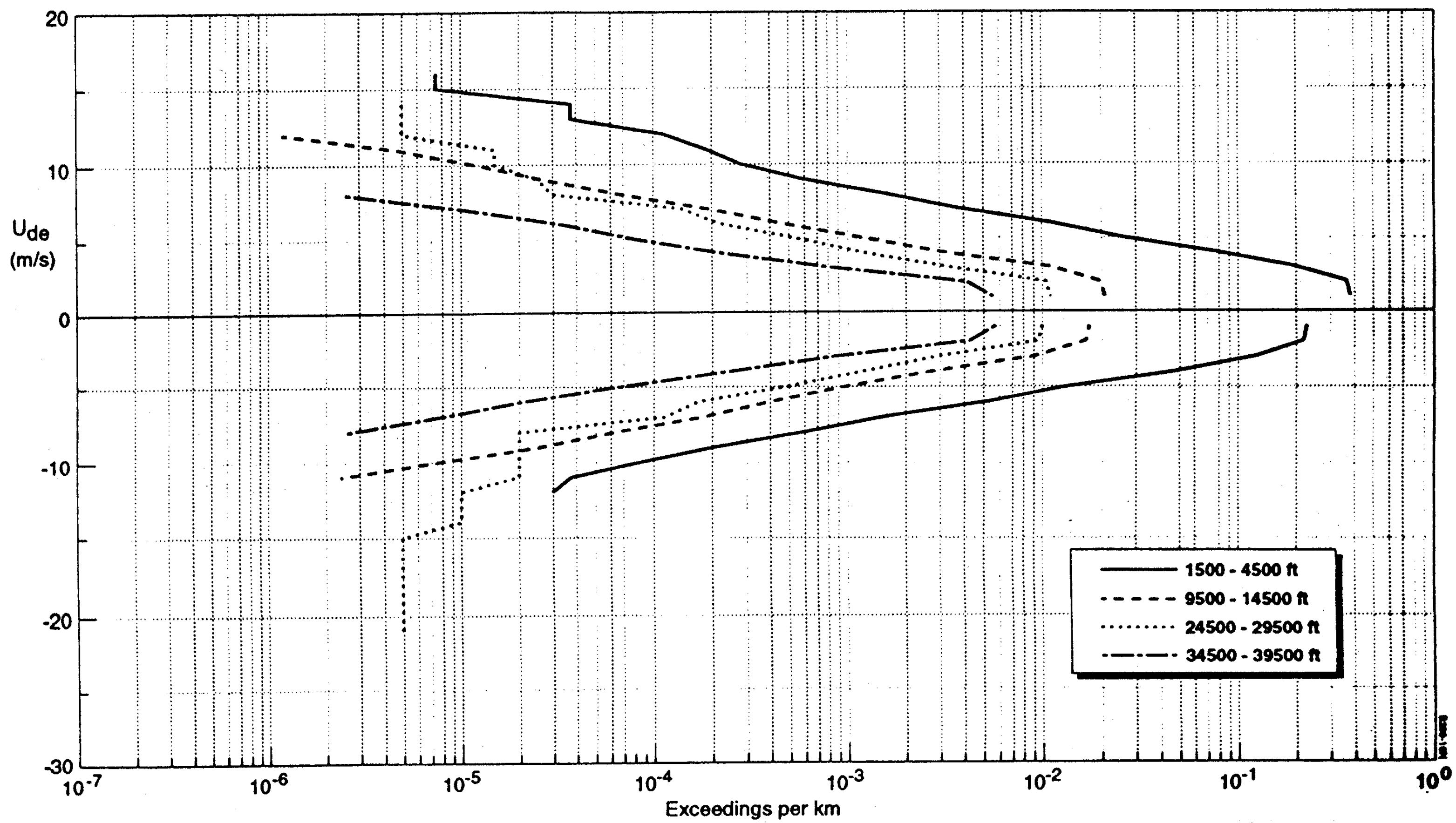

FIGURE 10. FATIGUEMETER DATA BASE: U_{de}-EXCEEDANCES PER KM FOR FOUR ALTITUDE BANDS

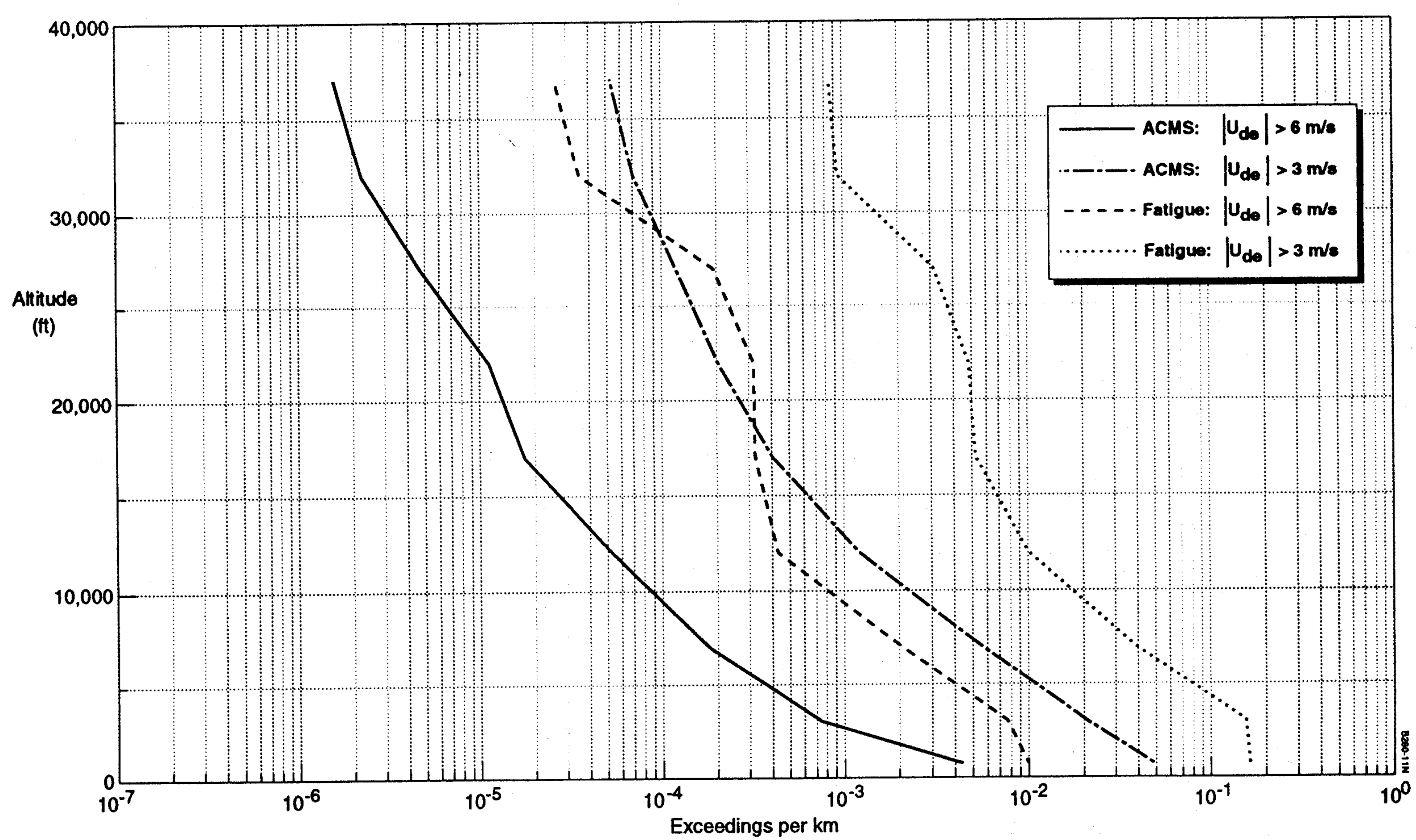

FIGURE 11. EXCEEDANCES FREQUENCIES OF TWO GUST VELOCITIES AS A FUNCTION OF ALTITUDE, PERTAINING TO TWO DATA BASES

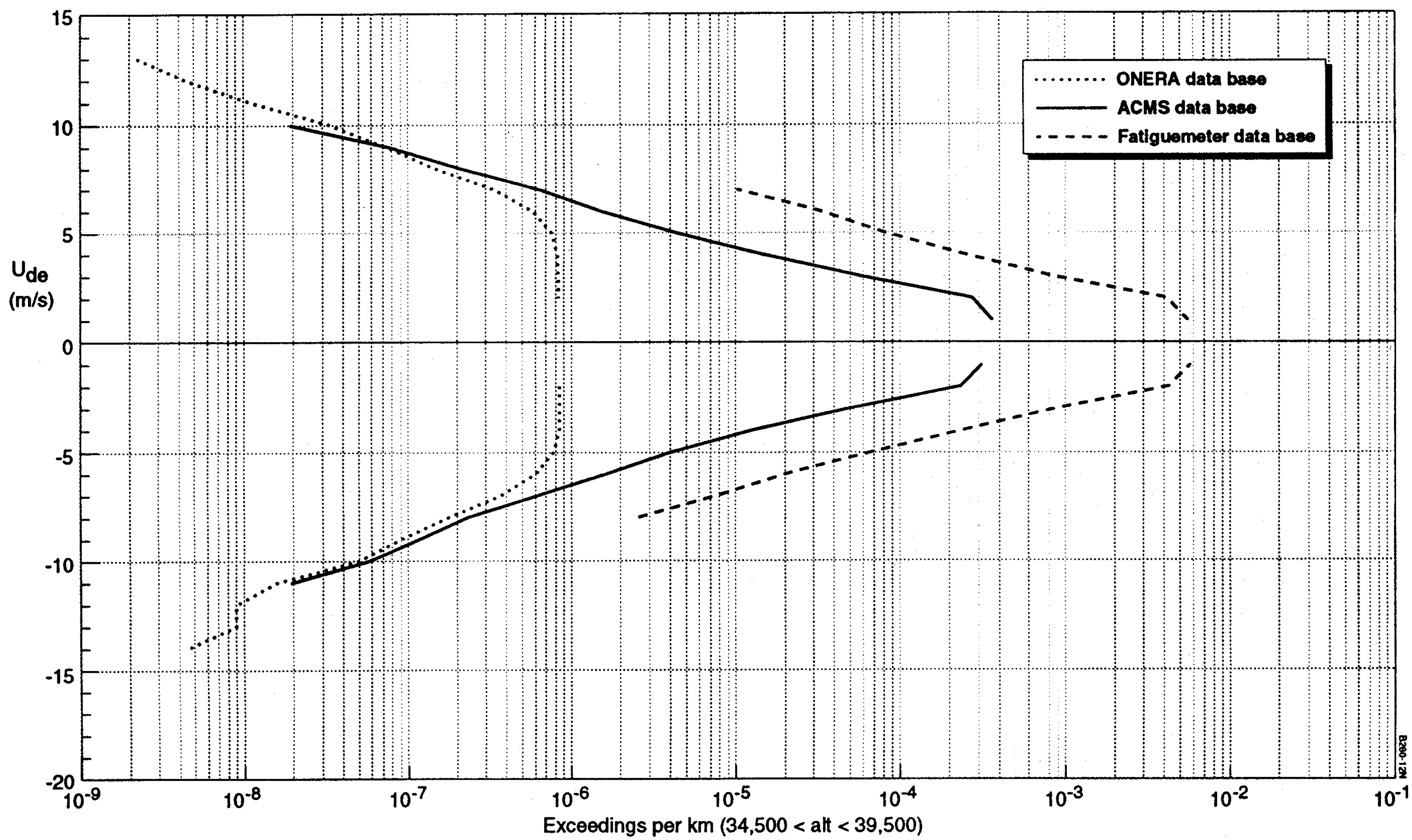

FIGURE 12. EXAMPLES OF FIT OF U_{de} EXCEEDANCE CURVES FROM THREE DATA BASES: SMOOTH FIT OF ONERA AND ACMS DATA

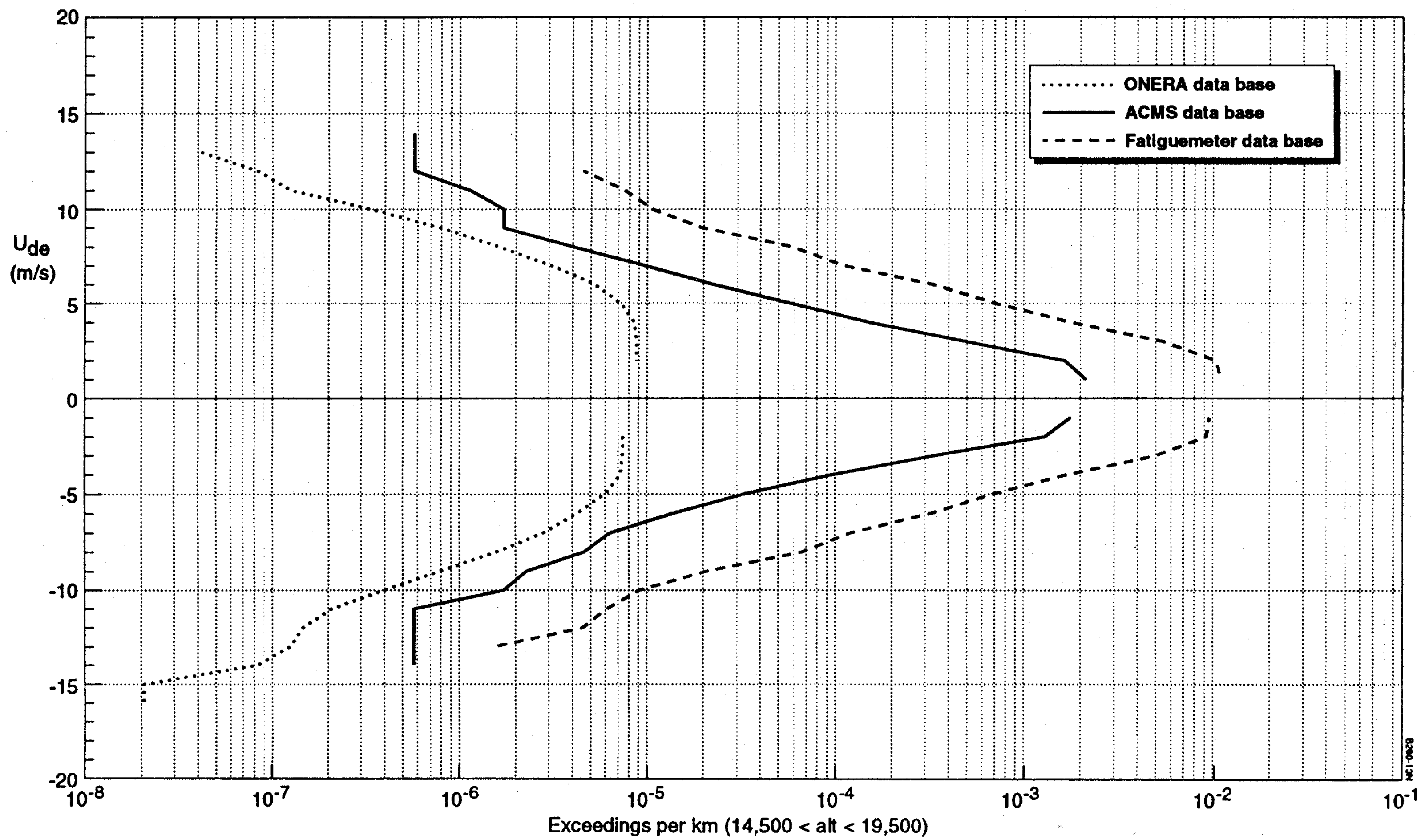

FIGURE 13. EXAMPLES OF FIT OF U_{de} EXCEEDANCE CURVES FROM THREE DATA BASES: SHIFT OF ONERA CURVE TO THE RIGHT TO OBTAIN FIT WITH ACMS CURVE

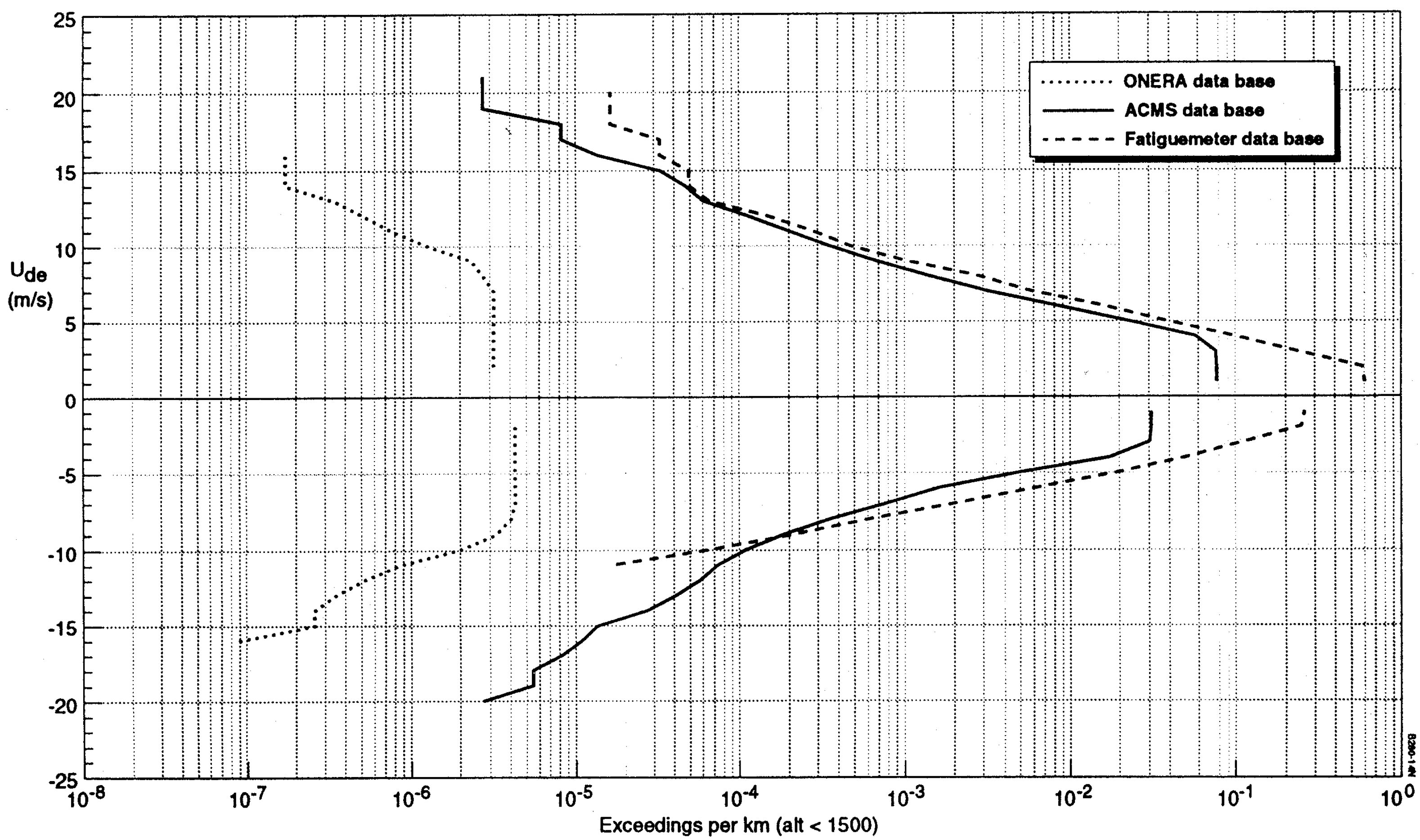

FIGURE 14. U_{de} EXCEEDANCE CURVES FROM THE ALTITUDE BAND 0-1500 FT.

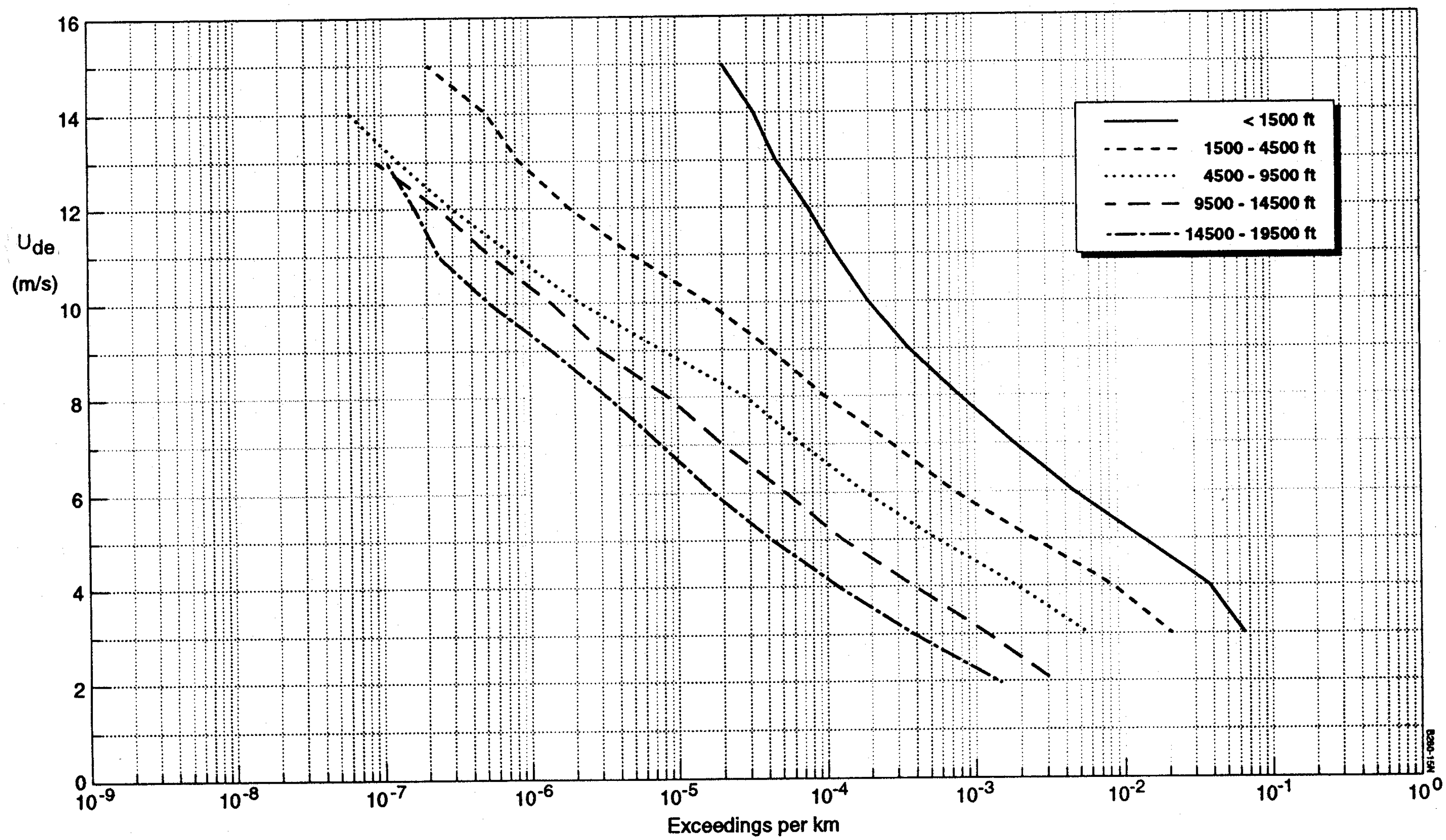

FIGURE 15A. U_{de} EXCEEDANCE CURVES FOR THE FIVE LOWEST ALTITUDE BANDS

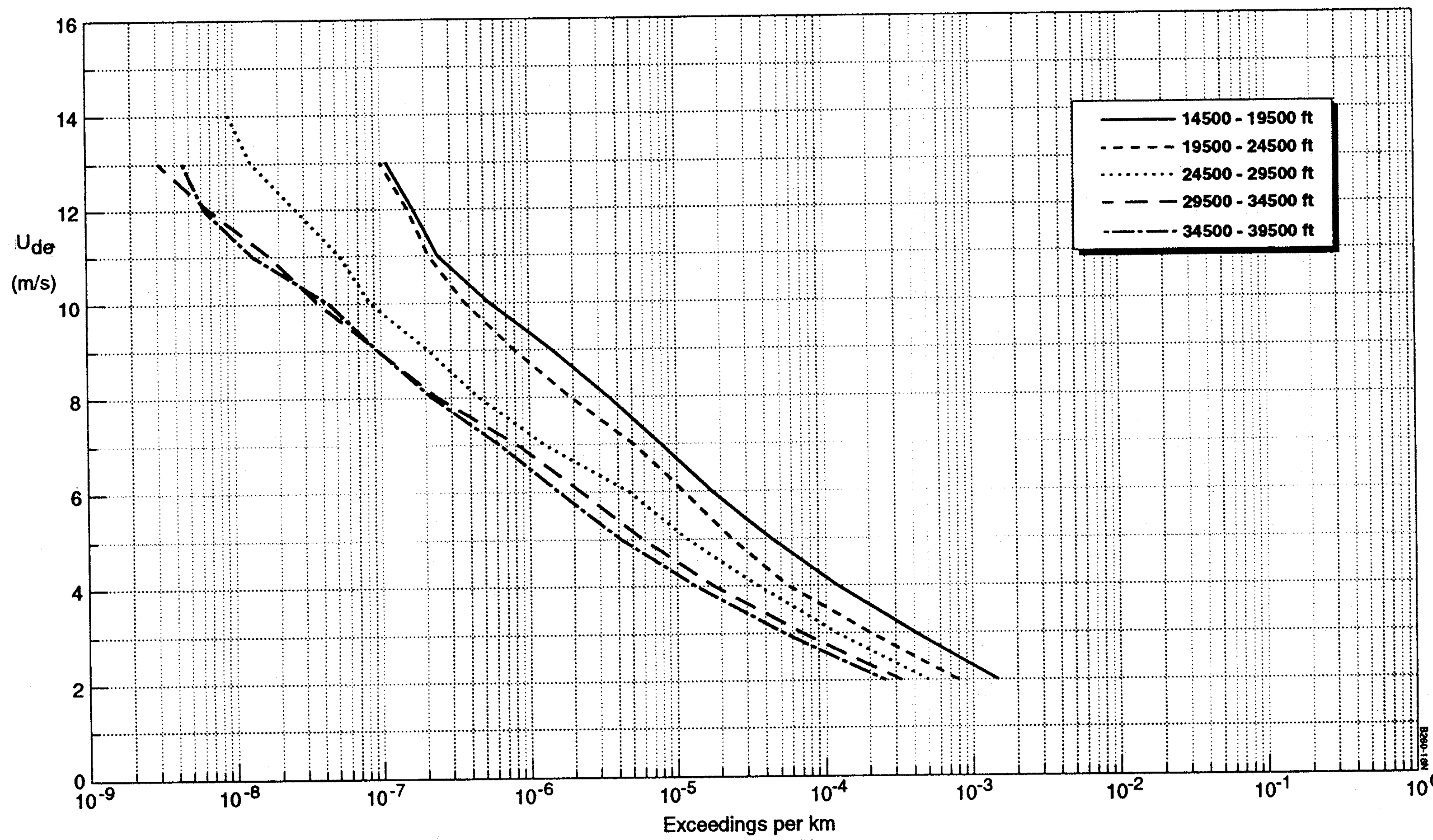

FIGURE 15B. U_{de} EXCEEDANCE CURVES FOR THE FIVE HIGHEST ALTITUDE BANDS

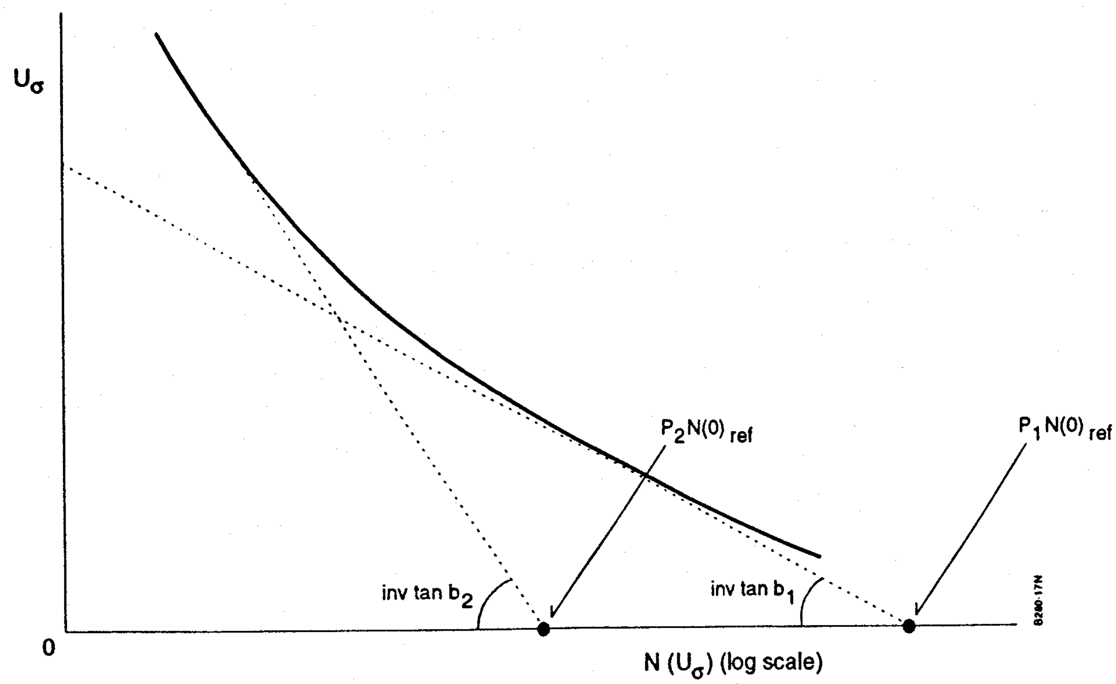

FIGURE 16. ESTIMATION OF PARAMETERS P_1, P_2 AND b_1, b_2 FROM THE U_σ EXCEEDANCE CURVE

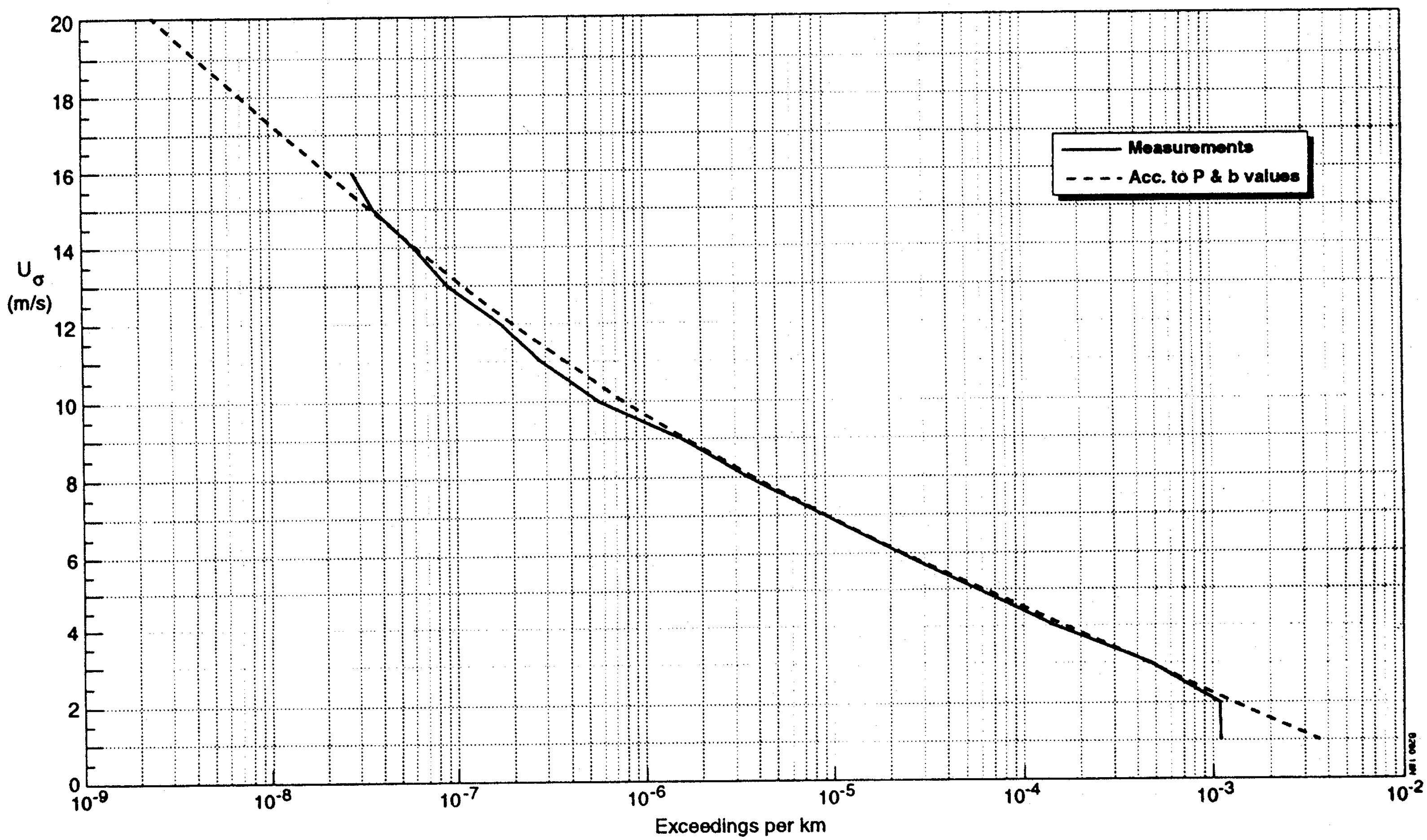

FIGURE 17. APPROXIMATION OF U_σ EXCEEDANCE CURVES BY CURVE DEFINED THROUGH P-b VALUES

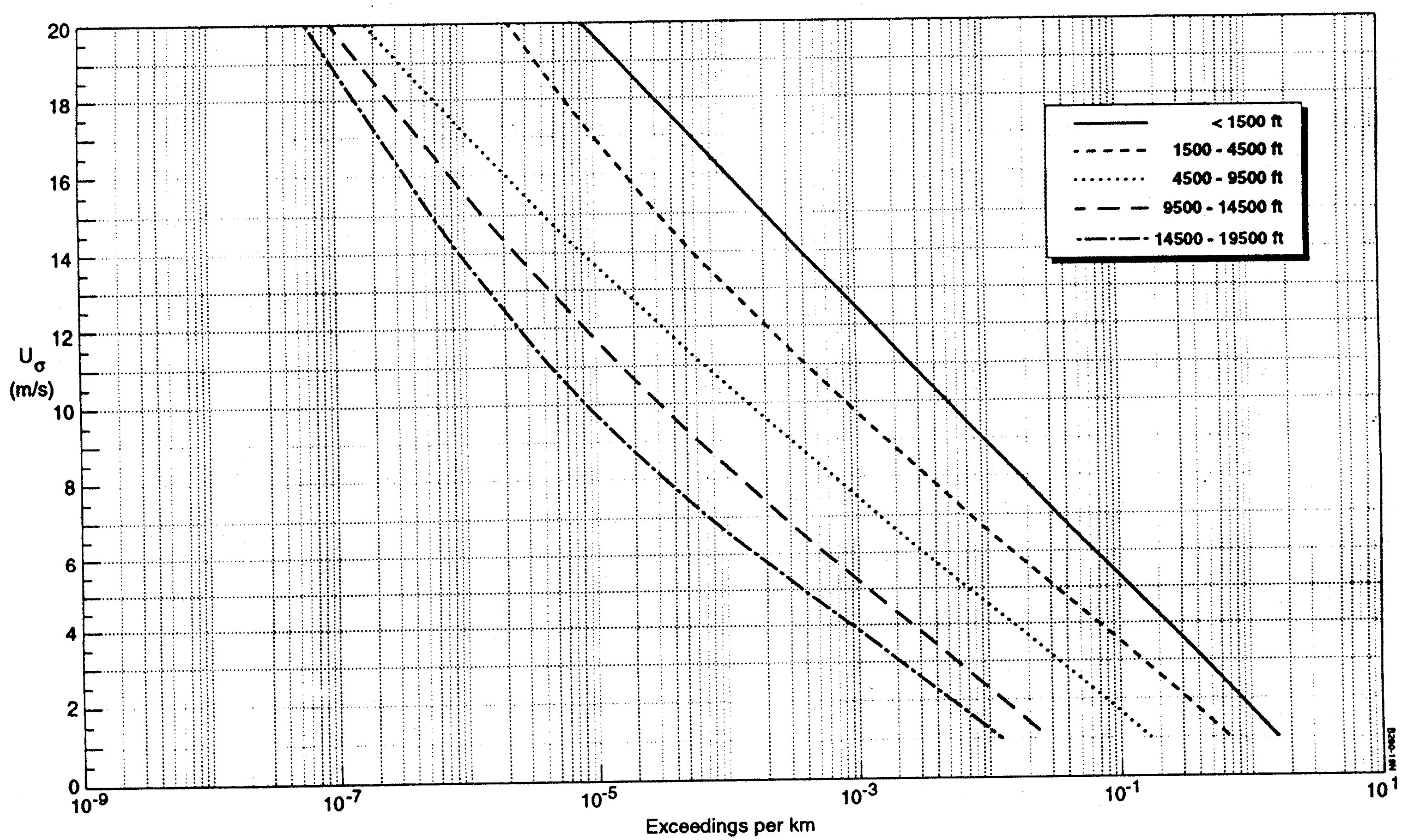

FIGURE 18. U_σ EXCEEDANCE CURVES FOR FIVE LOWEST ALTITUDE BANDS $[N_0(0)=8\ KM^{-1}]$

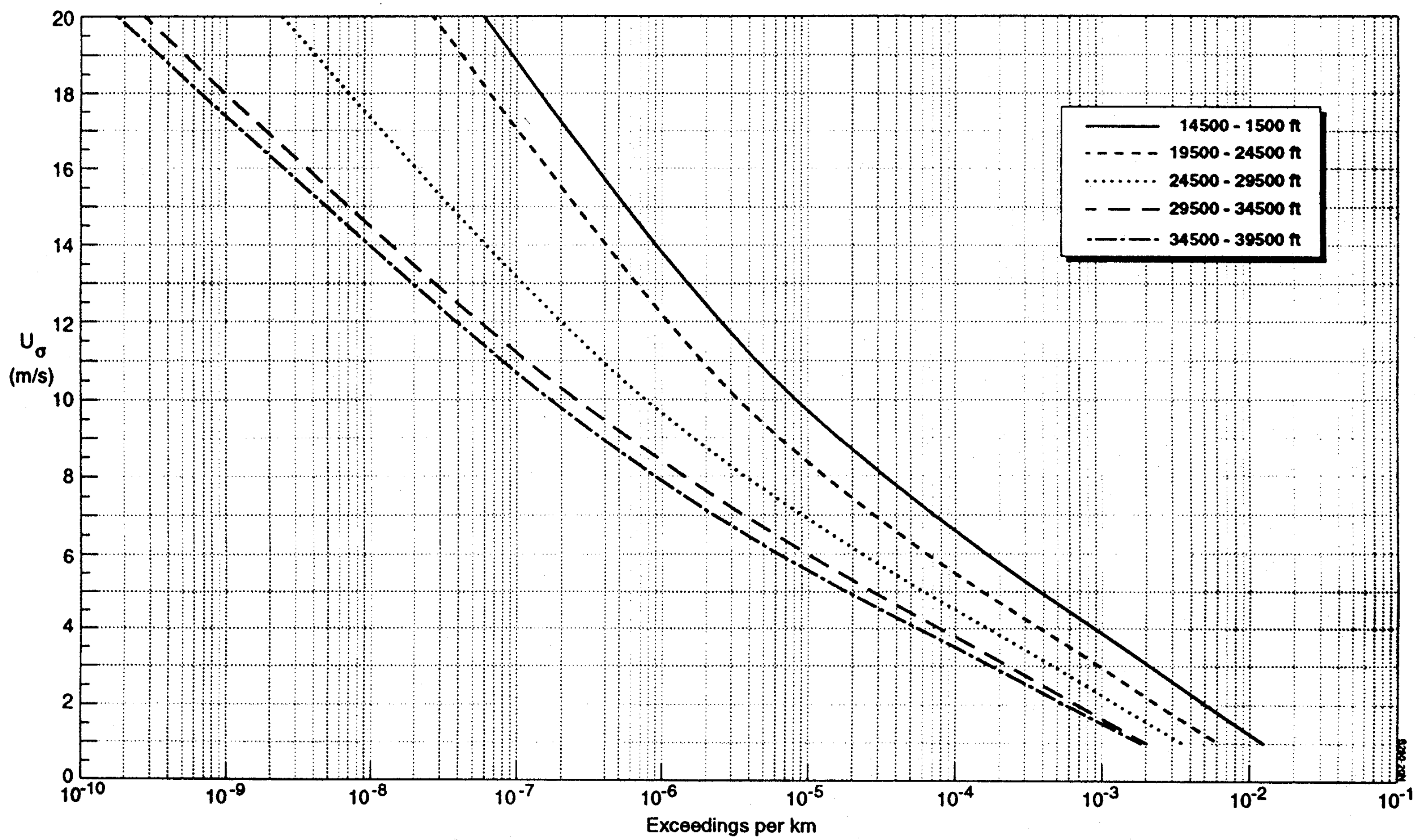

FIGURE 19. U_σ EXCEEDANCE CURVES FOR FIVE HIGHEST ALTITUDE BANDS $[N_0(0)=8\ KM^{-1}]$

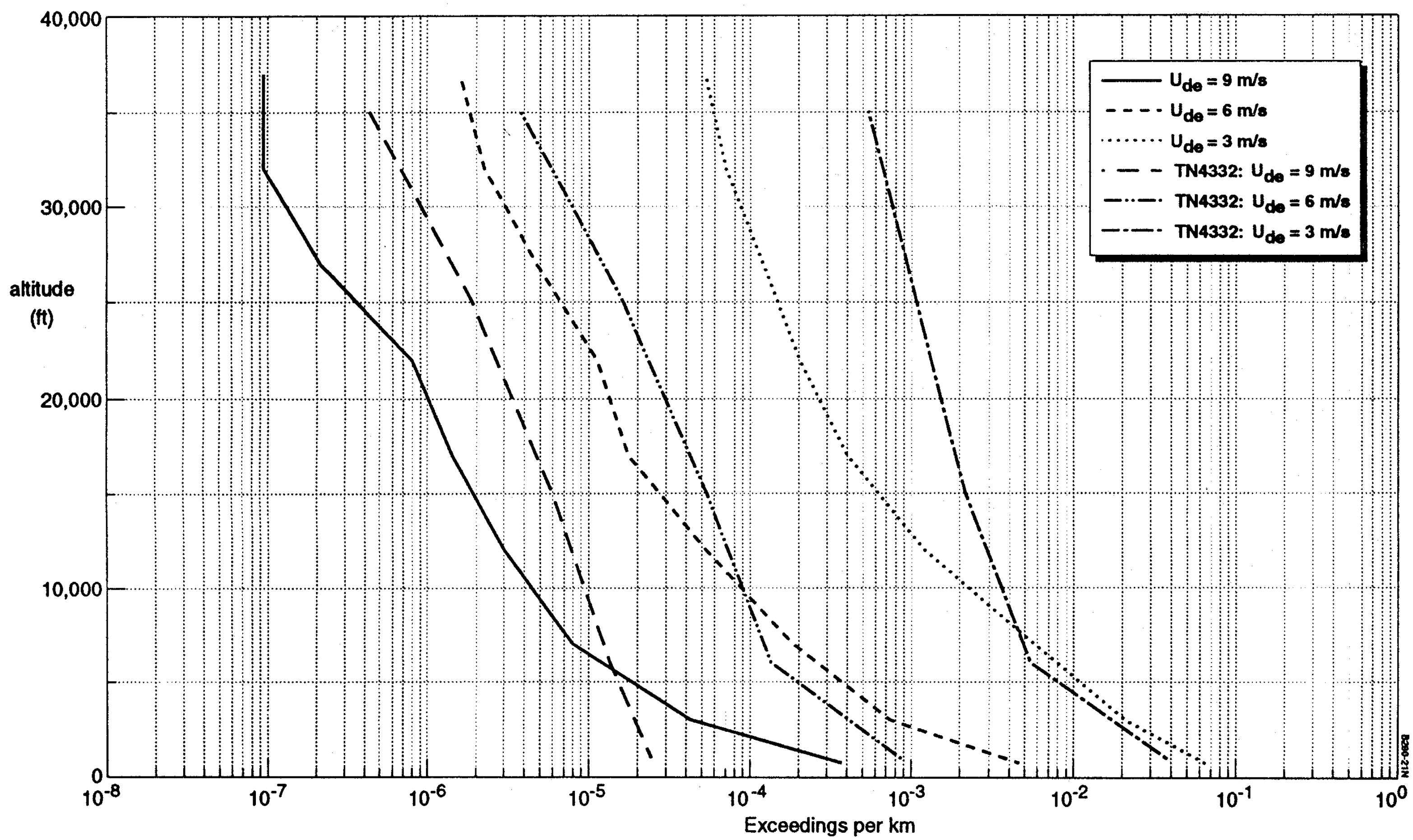

FIGURE 20. COMPARISON OF U_{de} EXCEEDANCE FIGURES NACA TN4332

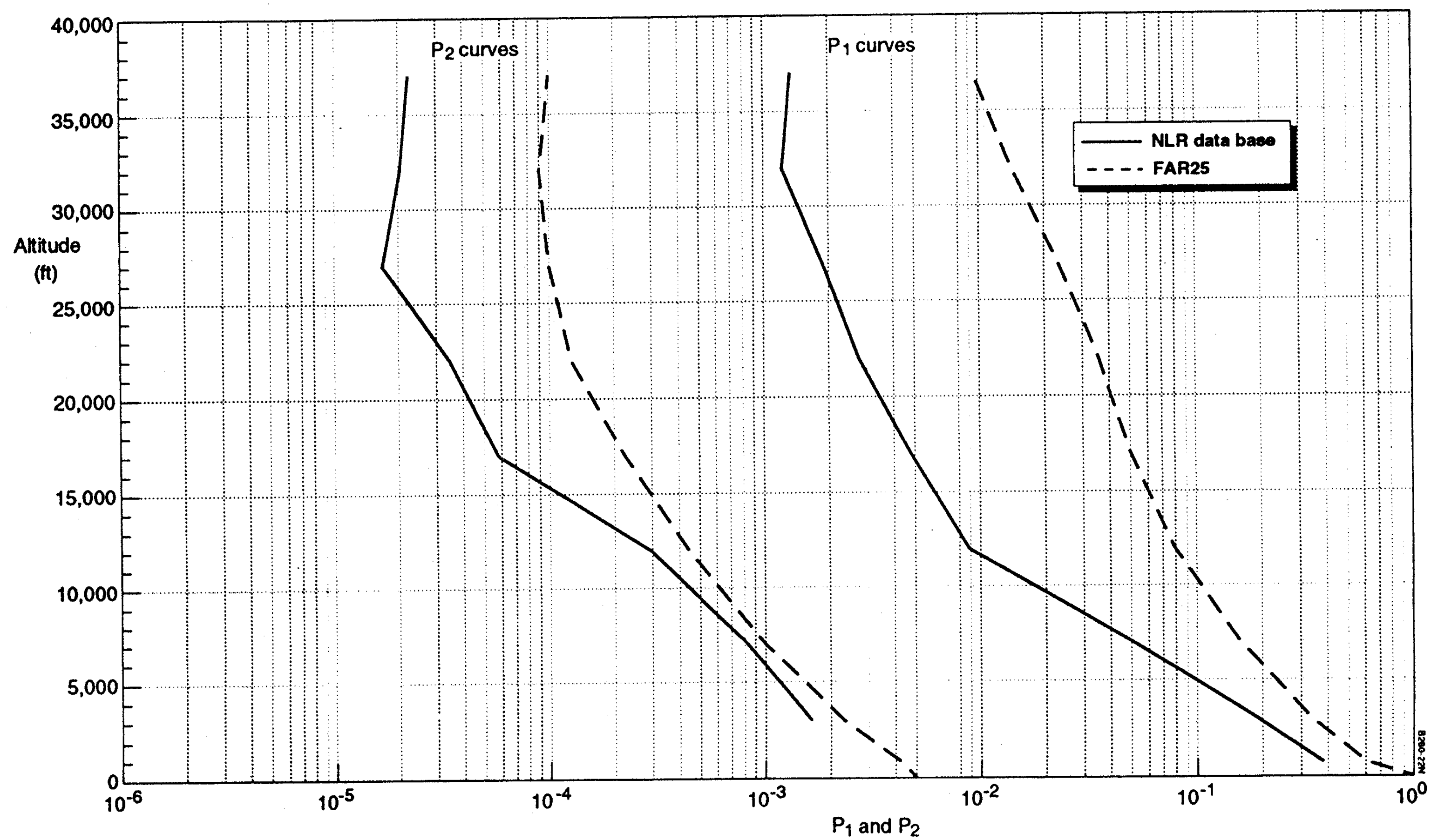

FIGURE 21. COMPARISON OF P-VALUES WITH FAR FIGURES

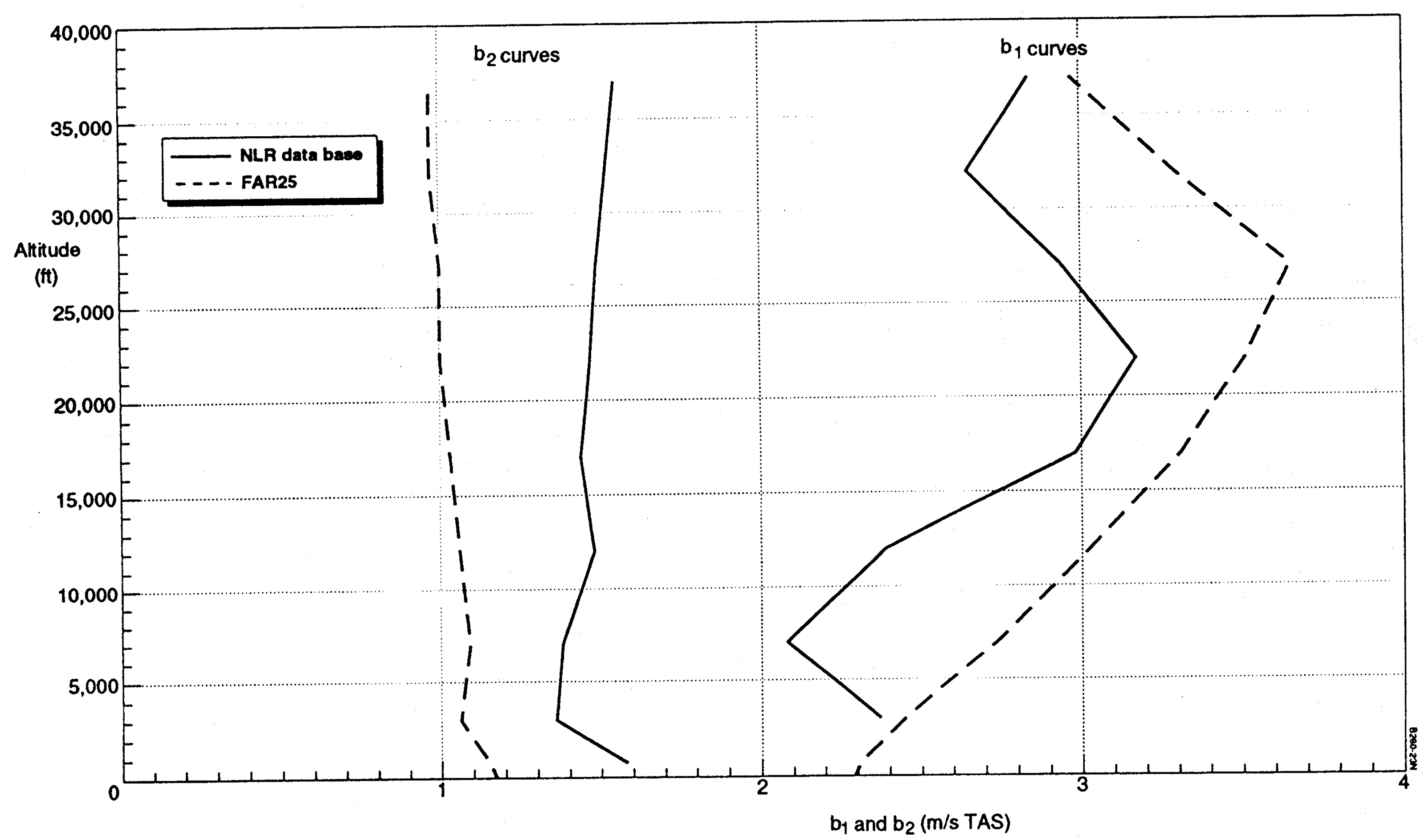

FIGURE 22. COMPARISON OF b-VALUES WITH FAR FIGURES

APPENDIX A—SUMMARY OF REDUCTION PROCEDURES

1. REDUCTION OF ACCELERATIONS TO GUST VELOCITIES.

The classified acceleration peaks and valleys Δn_z are reduced to "derived gust velocities", following a discrete gust approach and PSD-gust approach respectively:

1.1 DISCRETE GUST.

Each single Δn_z is reduced to one "gust" U_{de} according to:

$$U_{de} = \frac{\Delta n_z}{\overline{C}} \tag{A.1}$$

$$\text{with:} \quad \overline{C} = \frac{\rho_0 V_E C_{L\alpha}}{2\ mg/S} \bullet F(\mu_g) \tag{A.2}$$

$$\text{where} \quad F(\mu_g) = \frac{.88\mu_g}{5.3 + \mu g} \tag{A.3}$$

1.2 PSD-GUST.

Each single Δn_z is reduced to $\frac{N_0(0)\,ref}{N_0(0)}$ "gusts" with magnitude U_σ, according to

$$U_\sigma = \frac{\Delta n_z}{\overline{A}} \tag{A.4}$$

$$\text{with} \quad \overline{A} = \frac{\rho_0 V_E C_{L\alpha}}{2\ mg/S} \bullet F(PSD)$$

$$\text{where} \quad F\ (PSD) = \frac{11.8}{\sqrt{\Pi}} \left(\frac{c}{2L}\right)^{\frac{1}{3}} \sqrt{\frac{\mu_g}{110 + \mu_g}} \tag{A.6}$$

2. DEFINITION OF ALTITUDE BANDS.

The altitude bands considered in the present analysis are the same as those that will be considered in the analysis of the US Flight Load Data to be gathered in the FAA Flight Loads Program. Note that these bands are slightly different from those originally proposed in reference 1.

Altitude Bands (feet):

		<1500
1500	-	4500
4500	-	9500
9500	-	14500
14500	-	19500
19500	-	24500
24500	-	29500
29500	-	34500
34500	-	39500
> 39500	-	

APPENDIX B $C_{L\alpha}$ —CALCULATION FOR REDUCTION OF ACMS B-747 DATA

$C_{L\alpha}$ is calculated as a function of M, ρa^2, C_L and flap position

$$C_{L_\alpha} = \frac{C_{L_\alpha rig}}{1 + C_{L_\alpha rig}\left[\frac{1}{2}\rho a^2 M^2 K_L - \frac{K_n}{C_L}\right]} + \Delta C_{L_\alpha flap}$$

with, for the B-747 aircraft, $K_L = 1.23 \times 10^{-4}$ ($m^2.N^{-1}$. degrees)
$K_n = 0.31$ (degrees)

where $C_{L\alpha\ rig}$ is the following function of Mach number:

M	$C_{L\alpha\ rig}$ (degree^{-1})
0.30	0.087
0.40	0.088
0.50	0.090
0.60	0.092
0.70	0.093
0.80	0.094
0.85	0.101
0.90	0.118

In the configuration with flaps down the $C_{L\alpha}$ value is considerably higher than with flaps up. To calculate the increase in lift curve slope as a function of flap angle the following table is used:

Flap angle (degree)	$\Delta C_{L\alpha\ flap}$ (degree^{-1})
0	0.000
1	0.005
5	0.015
10	0.017
20	0.019
25	0.020
30	0.020

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